The Skeletal and Muscular Systems

Lesson 2

ASSIGNMENT 4: ORGANIZATION OF THE SKELETON

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 153–160. Then read Assignment 4 in this study guide.

In this section, we'll focus on the anatomy of the skeletal system. We'll examine the purpose of each bone, compare similar bones found in different animals, and correlate the structure of each bone with its function. The skeleton includes hundreds of bones. Fortunately for your study, many of these are duplicated within the body, and many are similar across species.

Functions of Bone

Stop and think about the bones in your body. What do they do? You might think they simply support the body and its organs. But your bones are much more active than that. They act as points of attachment for your muscles as well as levers for muscle action. Your skeleton is made up of your bones. Without this framework of bones, your muscles couldn't move your body parts as efficiently or quickly. Imagine how difficult it would be to lift a heavy object without the help of your skeleton. No matter how strong your muscles may be, they don't work well without your bones. Your bones strengthen your body against injury and protect your internal organs. For example, your brain is protected by your skull, and your heart and lungs are protected by your rib cage. Bones also have metabolic functions. *Metabolic functions* are processes that deal with the buildup or break-down of living cells for the purposes of providing energy and facilitating growth. One important metabolic function of bones is the storage of minerals—especially calcium and phosphorus, two minerals found in food. Bones also store fat, but the amount stored is very small compared with other fat stores in your body.

Your bones are also a site for production of blood cells. Red blood cells, white blood cells, and platelets are all produced in *bone marrow,* a cavity in the middle of the bone. *Long bones* (e.g., those in the legs and arms) and certain *flat bones* (e.g., those in the pelvis) have larger marrow cavities. Therefore, these bones produce more blood cells. The amount of marrow available to produce blood cells declines with age. In addition, certain diseases can affect the bone marrow and cause a decrease in blood cell protection.

Bone Structure

Bone exists in one of two forms: cancellous bone and compact bone. *Cancellous bone* is a somewhat irregularly arranged group of bony material plates called *trabeculae* found in the bone marrow cavity. Bone marrow cells and extracellular substances are arranged on these plates. The cancellous bone provides a framework upon which the bone marrow material can perform its function. Cancellous bone also includes spinelike pieces of bony material called *spicules.* The spicules and trabeculae are arranged along lines of stress and force.

Cancellous bone provides strength. In addition, the arrangement of the trabeculae and spicules is loose enough to be somewhat compressible, so cancellous bone acts as a shock-absorbing tissue.

Compact bone is a more highly structured series of bone layers found in the outer portions of the bone. Compact bone is composed of a series of tubelike structures arranged so that the tube shafts are parallel to the bone shaft. In the center of each tube is a space called the *haversian canal.* This is the route through which blood vessels, lymphatic vessels, and nerves travel through compact bone. Several layers of bone are arranged in concentric circles around the haversian canal.

Each bone layer is called a *lamella* (plural, *lamellae*). Interspersed between the lamellae at random intervals are small spaces called *lacunae,* where osteocytes reside.

The lacunae extend as fine channels called *canaliculi* that reach to nearby lacunae and the haversian canal. Other channels called *Volkmann's canals* extend from the haversian canals at right angles and connect one haversian canal to another. Volkmann's canals are like haversian canals in that they carry nerves, blood vessels, and lymphatic vessels. Several layers of lamellae surround the haversian canal.

Collectively, the haversian canal, lamellae, lacunae, and Volkmann's canal are called a *haversian system.* Many haversian systems are arranged side by side within the compact bone. A series of tubes arranged in this fashion provides strength without excessive weight. The arrangement of canals and canaliculi allows for movement of blood, nutrients, and nerve signals to the osteocytes in the most efficient manner possible. The structure of compact bone maximizes strength while minimizing weight and allowing for some flexibility.

At the outer surface of the bone, the haversian systems give way to layers of lamellae that encircle the entire circumference of the bone. These layers of lamellae are collectively called *cortical bone.* A similar but looser arrangement of lamellae are found on the inside of the bone, next to the haversian systems that lie next to the bone marrow cavity. Figure 6-2 on page 156 of your textbook shows the structure of both cancellous and compact bone.

Bone Cells

Three types of cells are present in bone: osteoblasts, osteocytes, and osteoclasts. *Osteoblasts* are responsible for secreting the material that forms bone. As osteoblasts age, they become *osteocytes,* the primary cells of mature bone. However, under the proper conditions, osteocytes can revert to osteoblasts and begin forming bone again. This occurs when a bone is damaged (i.e., broken).

Osteoclast cells are actually destructive, dissolving bone around them when needed. Think of osteoclasts as the bone's demolition team and the osteoblasts as the construction workers who reconstruct the bone. In a growing animal, the three types of cells are very active. The bones of a maturing animal are constantly growing as osteoblasts deposit more bone, which then mineralizes.

If your bones grew only by deposition and mineralization of material from osteoblasts, they would be very thick and heavy. Osteoclasts prevent this by removing interior bone as the osteoblasts deposit bone on the outer ends of the bone. As a result, a bone's interior is relatively hollow, whereas the outside of the bone is strong. This makes the bone lighter without significantly compromising its strength. If your bones were full instead of hollow, they would be only slightly stronger but considerably heavier. This means you would be heavier and slower, and your muscles would have to be much stronger to accomplish the same tasks.

Bone Shapes

The four basic shapes of bone are long, short, flat, and irregular (see Figure 6-5 on page 159 of your textbook). *Long bones* are those that are longer than they are wide. Nearly all bones in the limbs are this shape. The ends of the long bones are called the epiphysis, and the shaft of the bone is called the *diaphysis. Short bones* are cube-shaped. Many of the bones in the feet are this shape. *Flat bones* are thin and flat with cancellous bone between two thin plates of compact bone. The scapula and many of the skull bones are flat bones. *Irregular bones* are simply those whose shapes don't fit any of the previous categories or have characteristics of more than one of the shape categories. An example is the patella bone that makes up the kneecap.

Bone Development

Bones develop in two ways. The first is *intramembranous ossification.* This occurs in the facial bones of the skull and the bones of the jaw, when bone material is deposited into a membrane-like mesoderm tissue called the *mesenchyme.* The second type of ossification is *endochondral ossification.* This occurs in the bones of the legs, ribs, spine, and pelvis as well as certain bones at the base of the skull. In endochondral ossification, connective tissue called *cartilage* develops and is gradually replaced by bone tissue. At each end of a long bone, the cartilage expands and ossifies. Two layers of cartilage remain on the bone's surface at each end of the long bone. Primary growth occurs in the *diaphysis,* whereas secondary growth forms at the *epiphysis* (plural, *epiphyses*).

Between each end of the diaphysis and each epiphysis is a zone of growth called the *epiphyseal plates* (or *growth plates*) (see Figure 6-3 on page 157 of your textbook). As you grow and hormones are released in your body, your growth plates eventually stop growing and become calcified. This fuses the diaphysis and epiphyses and results in an increase in the bone's length.

The bone's diameter (i.e., width) expands as a result of outward growth of the primary and secondary centers of ossification. This growth occurs as new bone is deposited on the outside and old bone is reabsorbed on the inside. This keeps the bone's thickness relatively constant.

Some bones, like those in the pelvis, begin as multiple growth areas that fuse together with age and have no distinct epiphyses. The number of growth centers for any given bone, the age at which these centers first appear, and the age at which the growth plates fuse varies by animal species as well as the type and location of the bone.

Bone Marrow

You may have noticed when you've seen a bone (e.g., ribeye steak cut in cross section) that the bone has a middle area of dark red-brown tissue surrounded by a ring of bone. This area in the middle of the bone is the bone marrow cavity. The reddish tissue is bone marrow. Early in life, all bones contain *bone marrow,* a very active tissue composed of many stem cells. Marrow is chiefly responsible for producing blood cells (e.g., red blood cells, white blood cells, and platelets) from the stem cells. The large number of red blood cells produced gives the early bone marrow a red color—hence the name *red marrow.*

The *stem cells* are supported by the bony framework of cancellous bone as well as the extracellular material of the bone marrow. The chief extracellular material within bone marrow is *reticulin,* a type of collagen that forms a very fine network of fibers in which the stem cells are interspersed. As blood cells mature, they enter vascular spaces in the bone marrow called *sinusoids.* The sinusoids in turn empty into veins that carry the newly formed cells into the general circulation.

With aging, there's less demand for blood cell production. More stem cells are replaced by fat-storing cells (*adipocytes*). Bone marrow in older animals contains so many adipocytes that it takes on a yellow color (i.e., *yellow marrow*). Under the right conditions (blood loss or other diseases in which the RBC count is low), bone marrow can revert from the less active yellow form to the more active red form.

As bone ages even more, the amount of stem cells decreases and the amount of adipocytes increases further, leading to formation of *white marrow,* which is incapable of reverting to red marrow. Animals with long life spans sometimes develop *gelatinous marrow,* a gel-like degraded form of marrow.

Introduction to Bone Terminology

Your textbook describes in detail the structure of each bone in various species. Different species have differences in bone structure because of the profound differences in how they move and use their bodies. You'll learn about the general structure and relationships between bones, including some specific details for individual species that are relevant to veterinary medicine.

Many of the terms used to describe the regions of bones are familiar to you: *medial, lateral, cranial, caudal, dorsal, ventral, proximal, distal.* However, some of the terms used to describe bones might be new.

Many of the bumps and spines on bones serve as attachment sites for muscles, because the skeletal system and the muscular system work together to move body parts. The features that are present on a particular bone help define the specific role of the bone.

Articular Surfaces

An *articular surface* is a surface that forms a joint and contacts (i.e., articulates with) another bone. Articular surfaces are covered with hyaline cartilage.

A *condyle* is a rounded end of a bone that articulates with another bone.

The *head* of a bone refers to the rounded articular surface or a long bone.

Flat articular surfaces are called *facets.*

Processes, Holes, and Depressed Areas

Processes are the various projections and bumps found on bones. They have a variety of names depending on their location. The processes on the vertebrae are simply called *spinous processes,* while those of the femur are called the *trochanter*. The process on the humerus is called a *tubercle,* and the ischium process is termed the *tuberosity.*

A *fossa* is a concave depression in a bone. Muscles are usually found in these areas.

A *foramen* (plural, foramina) is a natural opening or passageway through a bone. Often, blood vessels and nerves are present within the foramen of a bone.

Skeletal Classification

Bones of the skeleton can be divided into two major categories: the axial skeleton and the appendicular skeleton. The *axial skeleton* is the body's central framework along its long axis and includes the bones of the skull, spine, ribs, and sternum. The *appendicular skeleton* consists of the bones of the limbs, shoulders, and pelvis.

A minor component of the skeleton is the *visceral skeleton,* made up of small bones within soft tissue that don't connect directly to other bones. Although each of the visceral skeletal bones serves a specific function, they're relatively few in number. *Ligaments* are bands of tough, fibrous connective tissue that connect bones at joints, and *tendons* are bands of similar material that attach muscles to bones.

Before proceeding to the next assignment, take a moment to complete *Self-Check 4.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 4

1. *True or False?* Once osteoclasts are surrounded by bone, they're called *osteoblasts.*

2. *True or False?* The ends of long bones are called *epiphyses.*

3. *True or False?* Condyles are found on the distal ends of the femur, humerus, and scapula.

4. Compact bone consists of tightly compacted cylinders of bone called
   - a. canaliculi.
   - b. endosteum.
   - c. haversian systems.
   - d. Volkmann's canals.

5. Blood vessels pass through countless tiny channels in bone called
   - a. Volkmann's canals.
   - b. growth plates.
   - c. nutrient foramina.
   - d. condyles.

6. Intramembranous bone formation occurs only
   - a. at growth plates.
   - b. in the long bones.
   - c. at secondary growth centers.
   - d. in certain skull bones.

7. Which of the following is *true?*
   - a. Yellow bone marrow consists primarily of hematopoietic tissue.
   - b. Yellow bone marrow can revert to red bone marrow.
   - c. Yellow bone marrow makes up the majority of bone marrow of young animals.
   - d. Red bone marrow consists primarily of adipose connective tissue.

8. Which common bone feature is a somewhat spherical articular surface on the proximal end of long bones?
   - a. Head
   - b. Facet
   - c. Condyle
   - d. Fossa

(Continued)

Self-Check 4

9. The processes on the humerus are called

   a. tubercles.
   b. trochlea.
   c. sesamoids.
   d. spinous.

10. The processes on the femur are called

    a. tubercles.
    b. trochanters.
    c. sesamoids.
    d. spinous.

Check your answers with those on page 188.

ASSIGNMENT 5: THE AXIAL SKELETON

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 161–174, 423–424, and 475–476. Then read Assignment 5 in this study guide.

The axial skeleton includes the bones of the following structures:

- Skull
- Spine
- Ribs
- Sternum

The *axial skeleton* forms the central supporting structure for the body's organs. In addition to providing support, the bones of the axial skeleton provide protection for delicate structures such as the brain, spinal cord, heart, and lungs.

Skull

The *skull* is a collection of flat bones (as opposed to long bones) that are fused or hinged together to form a solid mass of bone. This bone performs the following functions:

- Protects the brain
- Forms the nasal passages and eye sockets
- Creates jawbones for biting and chewing

Skull bones also serve as sites of attachment for muscles of facial expression, chewing, swallowing, and head and neck movement.

Skulls are organized into two areas:

1. The *cranial cavity,* where the brain is located
2. The *facial bones,* which make up the nose, jaw, and eye sockets

Table 6-1 on page 161 on your textbook contains a summary of the bones of the cranial cavity and face.

The shapes and sizes of skull bones vary with the species of animal, giving each animal its distinctive head shape and serving slightly different functions in each species. For example, the differences in the faces of the many breeds of dogs are largely determined by differences in the shape and size of the skull bones.

Many bones make up the skull. We'll consider only a few of the most clinically relevant ones in this discussion.

The bones of the cranial cavity surround and protect the brain; most of these bones occur in pairs, one on each side of the skull. The unpaired bones don't have equal counterparts and are often found in the middle of the skull. Let's examine the major skull bones and their accompanying functional holes or openings (i.e., *foramina*) in those bones in the horse, cow, and cat (see Figure 6-9 on page 164, Figure 6-10 on page 165, and Figure 6-11 on page 166 in your textbook). Additional summary information related to birds, amphibians, and reptiles is included in the sections that follow.

The *occipital bone* is a single, unpaired bone of the caudal skull that has a large opening called the foramen magnum. The *foramen magnum* is the opening into the cranial cavity where the spinal cord passes through to connect with the brain. The two *occipital condyles* (large, rounded articular surfaces) of the skull articulate with the *atlas* (i.e., first cervical vertebra). The cranial cavity floor has several foramina for nerves to pass from the brain to the eyes and facial muscles. On the lateral aspect of the cranial cavity is the *temporal bone,* which also forms a bony cavity called the *tympanic bulla,* where the structures of the middle ear are located.

On the lateral side of the tympanic bulla is a large opening called the *external acoustic meatus.* In a living animal, the *tympanic membrane* (eardrum) extends across the external acoustic meatus, and the cartilage of the external ear canal attaches around it. The temporal bone also contains channels through which the nerves for hearing and balance pass on the way to the brain. A bony projection from the temporal bone forms the caudal part of the *zygomatic arch,* a bony arch that helps hold the eye in place and protects it from injury. You can feel the zygomatic arch on your dog or cat.

It's a bony ridge that extends roughly from the eye to the ear on the lateral margin of the skull. The lower jawbone, Jor mandible, articulates with a depression on the temporal bone called the *mandibular fossa* (or *condyloid fossa*).

Two bones form the roof of the cranial cavity: the *parietal bone* (caudally) and the *frontal bone* (rostrally). The frontal bone contains a projection that forms another part of the zygomatic arch. The frontal bone is also the bone to which the horns of cows, rams, and goats attach. A single unpaired bone called the *ethmoid bone* forms the rostral wall of the cranial cavity and has many small foramina for passage of the olfactory (i.e., sense of smell) nerves.

Within the nasal cavity lies a complex arrangement of coiled and folded sheets of thin bone covered in a moist mucous membrane. These bony scrolls are called *conchae* (or *turbinates*). The conchae warm and humidify the air as it's inhaled, help filter out debris from the air, and increase the surface area for the sense of smell. The *nasal septum* is a structure made of cartilage and bone that lies along the median plane in the nasal cavity and divides the left and right nasal passages from each other.

The other region of the skull consists of the facial bones. The *nasal bone* forms the bony roof of the nasal cavity, whereas the *lacrimal bone* forms the medial surface of the eye socket. The *maxilla* forms the upper jawbone and most of the hard palate, which is the bony roof of the mouth. The maxilla contains the sockets of the upper canine teeth and cheek teeth. Just rostral to the right and left maxilla are the *incisor bones,* which hold the front teeth (i.e., incisors). Caudal to the maxilla are the *zygomatic bones,* which form the rostral region of the zygomatic arch.

The *mandible* is the lower jaw, which is formed by two halves that come together centrally at the front of the face. This area where the two halves meet is called the *mandibular symphysis.* Fractures that separate the two halves of the mandible at the mandibular symphysis are fairly common in cats that are hit by a car or fall from a high place and receive a blow to the mandible.

Each half of the jaw has two main regions: the body of the mandible and the ramus. The *body of the mandible* is the horizontal portion where the teeth are located. The *ramus* of the mandible is the vertical part that articulates with the skull. The condyle of the mandible is the part of the ramus that forms the hinge joint with the temporal bone. Medial and dorsal to the condyle is the *coronoid process,* a large plate of bone where some of the chewing muscles attach. Closely associated with the bones of the skull is the *hyoid bone,* which is a structure made of bone and cartilage that forms a sling to support the larynx, pharynx, and tongue. The hyoid bone assists in the processes of swallowing and breathing.

Birds, Amphibians, and Reptiles

Avian skulls differ from mammals, in that they contain adaptations to make the skull lighter. The skull bones are thin and contain large eye sockets (see Figure 19-13 on page 424 of your textbook). Avian skulls also support a bill, rather than teeth, as in mammals. The bill articulates with small movable bones that allow for independent motion of the upper and lower bill.

Reptile skulls show extreme diversity in appearance and are classified as either *anapsid* skulls or *diapsid* skulls depending on the presence of temporal fossa (see Figure 20-31 on page 476 of your textbook). The skull bones of reptiles are more flexible than those of mammals and contain specialized bones that allow the mouth to open very wide. Amphibian skulls are also quite variable. In most common species, however, the skull is broad and fenestrated.

Vertebrae

The spine consists of a series of bony *vertebrae* (singular, *vertebra*) that extend along the long axis of the body from the skull to the end of the tail. The vertebrae act as a central support for the body and protect the spinal cord. The spine is flexible because there are many vertebrae with joints between successive pairs, allowing the spine to straighten and bend. Although specific structures of each vertebra vary depending on the species of animal and the location and function of that particular vertebra, the general structure is similar (see Figure 6-16 on page 170 of your textbook). Each vertebra has a body, which forms the bulk of the bone and the floor of the *spinal canal,* which is the tube formed by the chain of vertebrae in which the spinal column resides. Dorsal to the body of the vertebra is the *vertebral arch,* which surrounds the spinal canal laterally and dorsally. The hole formed by the body and the arch is called the *vertebral foramen.*

Each vertebra has various projections (or *processes*) for muscle attachment and articulation of the vertebrae with each other. In most vertebrae, the largest process is the *spinous process,* which rises vertically from the dorsal surface of the arch. On each side of the vertebra is a *transverse process.* The exact shapes of the vertebra and its processes vary with the location and function of that vertebra within the spinal column.

The spine can be divided into five regions. Starting at the head and moving to the tail, these regions are the

1. Cervical or neck vertebrae
2. Thoracic or chest vertebrae
3. Lumbar or lower-back vertebrae
4. Sacral or pelvic-area vertebrae
5. Coccygeal or tail vertebrae

The number of vertebrae in each region varies with the species of animal. Specific vertebrae are named by identifying the vertebra's region in the spine as well as its position (or number) going from a cranial to caudal direction within that region. For example, the most cranial vertebra in the thoracic region is called the first thoracic vertebra (sometimes abbreviated T1). The vertebra immediately caudal to this one would be T2.

Cervical Vertebrae

All mammals (even giraffes!) have seven *cervical vertebrae.* The first two are greatly modified and often referred to by specific names. The most cranial vertebra (C1) is called the *atlas.* This vertebra is named after Atlas, the Greek mythological figure who held up the heavens, because this bone supports the head. Unlike other vertebrae, the atlas is wide and flattened, lacks a spinous process, and includes large, transverse processes called *wings.*

The second cervical vertebra (C2) is the longest and is called the *axis,* because it's the major pivot point on which the head rotates. A cranial projection called the *dens* extends from the body of the axis to articulate with the atlas. In some dogs, the dens doesn't form well or becomes fractured, causing excessive motion at the joint between the atlas and axis, which can lead to pressure on the spinal cord and resultant pain.

Thoracic Vertebrae

The bodies of the *thoracic vertebrae* are short, with large spinous processes. The bodies of the thoracic vertebrae articulate with the head of the ribs, whereas the transverse processes of the thoracic vertebrae articulate with the tubercles of the ribs. Carnivores, cows, and sheep have 13 thoracic vertebrae, whereas horses have 18 and pigs have 14 or 15.

Lumbar Vertebrae

Lumbar vertebrae are dorsal to the abdomen. They have long transverse processes for attachment of the powerful lumbar muscles. The number of lumbar vertebrae varies among, and even within, species. Horses and cows usually have six lumbar vertebrae. Cats and dogs usually have seven. Goats, pigs, and sheep may have either six or seven.

Sacrum

The *sacrum* appears to be one bone but is in fact formed from the fusion of several vertebrae—three in dogs and cats; four in pigs, sheep, and goats; five in cows and horses. Within the sacrum there are numerous foramina through which nerves and blood vessels travel out from the vertebral canal. The sacrum attaches firmly to the right and left ilium of the pelvis.

Coccygeal Vertebrae

The *caudal,* or *coccygeal, vertebrae* make up the animal's tail. They vary in number depending on the size of the tail and the species being looked at. For example, Manx cats have a very short or absent tail and thus have few—if any—caudal vertebrae.

Birds, Reptiles and Amphibians

Avian species are unique in that the numbers of cervical vertebrae are variable (i.e., 25 in swans, 7 in parakeets), and the structure of these vertebrae is adapted to allow greater flexibility. The atlas also contains only one condyle, instead of the two seen in mammals. The thoracic, lumbar, and sacral vertebrae are quite rigid.

Reptiles also have highly flexible vertebral columns. The reptilian spinal column is divided into three regions—*presacral, sacral,* and *caudal,* rather than the five regions seen in mammals. In amphibian species, the numbers of vertebrae is widely variable and can be as few as six in some species and as many as 250 in others. The vertebral regions are often indistinct, and some species may also have fused vertebrae.

Ribs

The *ribs* (or *costae*) are associated with the thoracic vertebrae and form a protective cage around the heart and lungs. They also aid in the process of respiration. Each rib is a long, slender, curved bone with a head that articulates with both the caudal body of one thoracic vertebra and the cranial body of the adjacent vertebra. Each rib also articulates with the transverse process of the vertebra. Look at the illustration of the canine ribs and sternum in your textbook (Figure 6-22 on page 174 of your textbook).

The more cranial ribs (i.e., the first nine pair in dogs) attach ventrally to bars of hyaline cartilage called *costal cartilage,* which attach to the sternum, or breastbone (see Figure 6-22 on page 174 of your textbook). The costal cartilages of the more caudal ribs don't attach directly to the sternum but overlap each other to form the costal arch. The most caudal ribs may be completely unattached at their ventral edge; these are called *floating ribs.* The space between adjacent ribs is called the *intercostal space.* In this space lie *intercostal muscles* that connect the ribs and help the breathing process.

The *sternum* is a bone that lies medially on the ventral surface of the thorax. The sternum helps protect the contents of the chest and aids in the breathing process. The caudal end of the sternum ends in a cartilaginous structure called the *xyphoid process.* Feel your own ribs, costal cartilages, costal arch, and sternum; do the same on your pets to familiarize yourself with these structures.

Birds, Reptiles and Amphibians

Birds have a well-developed sternum with a concave shape that usually contains a structure called a *keel*. The sternum is the site where the flight muscles attach.

In some reptiles and amphibians, the ribs may be poorly developed, and a sternum may be absent. In certain species, a bony plate may serve as a sternum.

Before proceeding to the next assignment, take a moment to complete *Self-Check 5.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 5

Questions 1–6: Match the following terms with their definitions below by placing the letter of the best definition in the blank space next to each term.

_______	1. Axis	a. Caudal vertebrae
_______	2. Coccygeal vertebrae	b. Vertebrae dorsal to abdomen
_______	3. Sacral vertebrae	c. First cervical vertebrae
_______	4. Thoracic vertebrae	d. Vertebrae firmly attached to ilium
_______	5. Atlas	e. C2
_______	6. Lumbar vertebrae	f. Vertebrae associated with ribs

7. The bone that forms the lower jaw is called the ________.

8. Scrolls of bone in the canine nasal cavity are called ________, which help filter and moisten the air as it passes through the nose.

(Continued)

Self-Check 5

9. The bone that supports the base of the tongue and aids in swallowing is called the ________.

10. The most cranial nine pairs of ribs in the dog directly connect to the ________.

Check your answers with those on page 188.

ASSIGNMENT 6: THE APPENDICULAR AND VISCERAL SKELETON

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 175–190, 424–426, and 476–477. Then read Assignment 6 in this study guide.

The *visceral skeleton* refers to bones located within soft tissues. Some animals have no visceral bones. Examples of visceral bones include the os cordis, in cattle and sheep, and the os penis, in dogs. The *os cordis* is located within the heart of cattle and sheep and supports the heart valves. The *os penis* (see Figure 6-37 on page 185 of your textbook) is located in the penis of dogs and encloses the dorsal portion of the urethra. The *appendicular skeleton* is composed of the bones of the thoracic and pelvic limbs. Table 6-3 on page 175 of your textbook summarizes the bones of the appendicular skeleton.

Thoracic Limb Bones

In most animals, the *thoracic limbs* support the front end of the body. In humans, the thoracic limbs are the arms, and they're used primarily for grasping and manipulating objects. Primates, such as monkeys and apes, are some of the few animal species that can walk nearly upright on their pelvic limbs, which frees the thoracic limbs for other purposes.

Some animals have adapted the thoracic limbs for other sorts of locomotion. For example, the thoracic limbs of dolphins, whales, and seals have evolved into flippers for swimming, and the front limbs of bats have been modified for flight. Regardless of these differences in function and locomotion, the thoracic limbs of all mammals have the same fundamental design.

The bones of the thoracic limb, starting closest to the spine and ending near the foot, are the scapula, humerus, radius, ulna, carpal bones, metacarpal bones, and phalanges.

Scapula

The *scapula* is the shoulder blade. The scapula attaches the thoracic limb to the body wall and also serves as the pivot point for the *humerus* (i.e., upper arm). The scapula is a flat bone, roughly triangular in shape. One point of this triangle is directed ventrally, whereas the base of the triangle is directed dorsally. The medial side of the scapula rests against the rib cage. The lateral surface features a ridge, called the *spine of the scapula,* which projects laterally along almost the entire length of the bone (see Figure 6-24 on page 175 of your textbook). The spine of the scapula attaches some of the shoulder muscles.

The scapula's lateral surface is divided into two grooves by the spine of the scapula. The cranial (and slightly dorsal) groove is called the *supraspinous fossa* (*supra* = above), whereas the caudal (and slightly ventral) groove is the *infraspinous fossa* (*infra* = below). The fossa provides space for muscles to attach the scapula to the humerus. Hoofed animals (e.g., cows, horses, pigs) have a well-developed ridge of cartilage along the dorsal border of the scapula called the *scapular cartilage.*

Muscles and ligaments attach the dorsal surface and spine of the scapula to the thoracic spine and the medial surface to the rib cage. Other muscles attach the cranial border of the scapula to the neck and head. The scapula narrows near the ventral point; this is called the *neck* of the scapula. Just distal to the neck of the scapula, the bone flares out slightly and ends in a concave (dished) region called the *glenoid cavity.* This is the joint surface where the humerus articulates with the scapula.

Humerus

Just distal to the scapula is the *humerus,* better known as the upper arm in humans. The humerus connects distally to the lower leg bones—the *radius* and *ulna* (i.e., the forearm in humans). The humerus serves as a site of attachment for muscles that attach to the scapula and neck to allow the leg to be pulled forward or backward and the head and neck to be pulled down or to the side. The humerus is also a site of attachment for muscles, such as the *pectoral muscles,* that connect the thoracic limb to the sternum in the mid-ventral chest.

The humerus is a long bone with a cylindrical shape (see Figure 6-25 on page 175 of your textbook). It has knoblike rounded ends that serve as points of articulation with the scapula proximally to form the shoulder joint. The humerus also articulates with the radius and ulna distally at the elbow. The round, smooth proximal end that joins with the scapula is called the head of the humerus, and just below the head the bone narrows in a region called the neck. Cranial to the head of the humerus are two projections called the *greater tubercle* on the cranial and lateral surface, and the *lesser tubercle* on the medial surface. The tubercles serve as points of attachment for the pectoral muscles.

The shaft of the humerus spirals slightly as it travels distally, following the path of the muscles that travel over the humerus. The distal end of the humerus is made up of two condyles—the *lateral capitulum* and the *medial trochlea.* These rounded regions of bone articulate with the radius and ulna, respectively. Dogs have a small hole just above the condyle called the *supratrochlear foramen.* Just proximal and slightly caudal to the condyles are two projections that flare out to each side. These are called the *lateral epicondyle* and *medial epicondyle.* The epicondyles are attachment sites for muscles.

Radius and Ulna

Just distal to the humerus are two bones lying side by side called the *radius* and *ulna.* These bones form part of the thoracic limb known as the *forearm* in humans. The radius and ulna articulate with the humerus proximally to form the elbow joint. The radius and ulna articulate with the carpal bones distally and act as points of attachment for the muscles that control the elbow and carpal joints. In humans and some animals (e.g., dogs, cats, and pigs), the radius and ulna are distinct and separate bones. However, in other animals, like ruminants, the bones are partially fused together. In the horse, they're completely fused. The structural variation in these two bones across different species relates to the ways in which different species need to be able to move. Species that need to rotate the forearm (i.e., the movement that turns the palm up or down in humans) need two separate bones in this region. These separate bones can then pivot around each other and around the long axis of the leg. For a species like the horse that has a greater need for speed and stability in the legs, fusion of the radius and ulna provides greater stability by preventing this part of the limb from rotating. The horse can't rotate its lower leg as a cat can rotate its paw to lick the bottom of it. However, in an animal that evolved to run from predators, the fused radius and ulna provide stability with a minimum potential for twists and sprains.

In horses, the radius is a long bone slightly flattened on the cranial and caudal surfaces. The ulna in horses is attached to the caudolateral surface of the radius, and its shaft is incomplete distally. At its distal end, the ulna tapers and fuses to the radius.

In species in which the ulna remains separate from the radius (e.g., dogs and cats), the ulna is often longer than the radius. It may even be the longest single bone in the body. In the dog and cat, both the radius and ulna articulate with the carpal bones distally. The proximal part of the ulna is somewhat more caudal than the radius. At their distal ends, the radius is medial to the ulna. Between the radius and ulna is an *interosseous space.*

The most proximal part of the ulna is the *olecranon,* which is a very large tuberosity that serves as a point of attachment for the muscles that extend the elbow joint and thereby straighten the leg. The olecranon is the bony prominence you can feel at your elbow. Just distal to the olecranon is the *trochlear notch,* the curved surface that articulates with the humerus (remember that the humerus articulates with two bones on its distal end).

Carpal Bones

Carpal bones are a collection of small, somewhat cuboidal, bones that form much of the carpus (or wrist in people). In animals, the carpus isn't called a wrist, and in fact in horses it's inaccurately referred to as the "knee." It's the site where the front leg bends to push the foot upward and backward. There are generally eight carpal bones arranged in two rows of four bones each. However, in some species, or even in individual animals within a species, some of the carpal bones may be fused together to form one bone or some of these carpal bones may be missing.

The distal row of carpal bones is numbered from 1 to 4, starting with the medial bone and moving laterally. Pigs have all eight carpal bones. Dogs have fused radial and intermediate carpal bones, for a total of seven carpal bones. In ruminants, the first distal carpal bone is missing, and the second and the third are fused, for a total of six carpal bones. Horses often lack the first carpal bone and occasionally have a fifth distal carpal bone lying lateral and distal to the ulnar carpal bone, for a total of seven or eight carpal bones.

Only the accessory carpal bone attaches to muscles; the other carpal bones are pivot points for flexion and extension of the carpal joint and act as shock absorbers. Fractures of the carpal bones in performance horses can cause serious problems and often cause permanent lameness.

Metacarpal Bones

Distal to the carpal bones are the *metacarpal bones* (*meta* = beyond). The metacarpal bones are long bones lying side by side. In humans, these bones compose most of the palm of the hand. In animals there's quite a bit of variation among species in the metacarpal bones. The metacarpal bones in animals connect the carpal bones to the digits (or toes). All metacarpal bones have the basic long-bone structure: one diaphysis with two epiphyses, proximal and distal.

Up to five metacarpal bones lie side by side and are numbered from 1, the most medial, to 5, the most lateral. Like the carpal bones, some metacarpal bones are absent or fused in different species of animals, so the total number in each limb may be less than five. The numbering of the toes or digits is based on the evolutionary development of the metacarpals. Take the horse, for example. Even though only one metacarpal is fully developed in each limb, the one that's most developed is called the third metacarpal because the other metacarpals (i.e., those associated with digits 1, 2, 4, and 5) were lost or greatly reduced during evolution.

Horses completely lack the first and fifth metacarpal bones. The second and fourth metacarpal bones, commonly called the *splint bones,* are vestigial and very small compared with the large third metacarpal bone, which is also called the *cannon bone*. The third metacarpal is the main metacarpal that bears the animal's weight.

The second and fourth metacarpal bones in the horse lie medial and lateral (respectively) to the cannon bone and somewhat caudal to it. These splint bones may fracture in young horses. In other cases, the *interosseous ligament* that connects these bones to the third metacarpal bone may tear, leading to a type of inflammation and lameness that's commonly referred to as "splints" by horsemen. *Bucked shins* is an inflammation of the *periosteum* (fibrous membrane covering exteriors of bone except for joint surfaces) over the equine third metacarpal bone; this condition occurs on the cranial surface of the bone.

Humans, cats, and dogs each have five metacarpal bones. Pigs lack the first metacarpal bone, and their third and fourth metacarpal bones are longer than the outermost bones (i.e., the second and fifth) so that only the two middle toes are actually supporting the animal's weight. In cows and sheep, the first and second metacarpal bones are missing, the third and fourth are fused into one bone called the cannon bone, and the fifth metacarpal bone is very small.

Digits

The metacarpal bones articulate distally with the bones that correspond to human fingers, but in animals these bones are called *toes* or *digits.* The digits are numbered from 1, the most medial and corresponding to the human thumb, to 5, the most lateral. Again, depending on the species of animal, there may be fewer than five digits. Digits that don't bear weight are called paradigits (or dewclaws).

The bones of each digit are called *phalanges* (singular, *phalanx*). Each digit except the first is composed of three phalanges—proximal, intermediate, and distal. The first digit is composed of two phalanges. The digit ends distally with a horny claw, nail, or hoof that's associated with the distal phalanx.

Cats have five digits, but the first digit, which has only two phalanges, doesn't bear weight and is thus a dewclaw. Some cats have extra dewclaws and may have a total of six or even seven digits, a condition called *polydactyly.*

Dogs are similar to cats but may lack a dewclaw; or the dewclaw may be removed shortly after birth. According to breed standards, some breeds may be required to have dewclaws or even double dewclaws.

Pigs lack the entire first digit, have two dewclaws—the second and fifth digit—and bear weight on the third and fourth digits. Ruminants are similar to pigs, but their dewclaws contain very small, irregular phalanges that reside in soft tissue without articulating with any metacarpal bones. This structure occurs because the second metacarpal is absent, and the fifth metacarpal bone is very small in ruminants.

Horses have only one digit—the third—that bears all of the weight for the thoracic limb. The common name for the equine proximal phalanx is the *long pastern bone;* the second phalanx is called the *short pastern bone;* and the distal phalanx is called the *coffin bone.*

The directional terms change slightly for structures distal to the carpus. The upper surface of the metacarpals and digits is called the *dorsal surface;* the lower surface that faces or touches the ground is called the *palmar surface.*

Sesamoid Bones

In addition to the phalanges, the digits also possess *sesamoid bones*. These are small nodular bones near a joint. These bones are sometimes embedded in the tendons of muscles that flex (bend) or extend (straighten) the digits. Some sesamoid bones increase leverage for the muscle pulling on the tendon in which the sesamoid is embedded; this increased leverage clearly provides a biomechanical advantage to the muscle. Other sesamoids have no clear function; these bones may be residual bones that have lost their function as the animal evolved. Most sesamoid bones in the digits are located on the palmar surface of the joints.

Horses have two proximal sesamoid bones located behind the distal articular surfaces of the third metacarpal bone, and one distal sesamoid bone located behind the junction of the intermediate and distal phalanges. The proximal sesamoid bones in the horse sometimes fracture, whereas the distal sesamoid bone in the horse—commonly called the *navicular bone*—may develop a type of lameness called *navicular disease.* Dogs have up to 13 sesamoid bones in each front paw at the metacarpophalangeal joints. Cats have nine sesamoid bones on the palmar surface of the metacarpophalangeal joints in the front paw.

Birds, Reptiles, and Amphibians

In birds, reptiles, and amphibians, the thoracic limb is referred to as the *pectoral girdle.* The pectoral girdle of birds consists of the paired scapulas, coracoids, and clavicles (see Figure 19-14 on page 425 of your textbook). The wing bones consist of the humerus, radius and ulna, the alula bone, metacarpal bones, and digits. The length of the humerus varies depending on the flight pattern of the species (i.e., soaring, flapping, etc.). The pelvic girdle of most reptiles is similar to that seen in mammals with small differences in the numbers of digits. Some species of snakes have vestigial limbs referred to as *spurs*.

Pelvic-Limb Bones

The pelvic limbs support the rear end of the body, and in most land animals the hind limbs are the main source of propulsion and strength when the animal runs or jumps. Some animals (as well as humans) have adapted their pelvic limbs so they can stand on them, freeing the thoracic limbs for actions such as grasping and climbing. Some climbing animals have even adapted their pelvic limbs to aid their thoracic limbs in grasping. Some aquatic mammals like whales and seals have lost or fused their pelvic limbs and possess only a tail-like appendage with flippers.

Like the thoracic limbs, the pelvic limbs have a basic organization that's similar between species. The fundamental bones of the pelvic limb, starting proximally and moving distally, include the following: pelvic bones (ilium, ischium, and pubis), femur, patella, tibia, fibula, tarsal bone, metatarsal bones, and phalanges.

Pelvic Bones

The pelvis is a girdle of bones that attach the spine to the pelvic limbs, similarly to the way in which the scapula attaches the thoracic limbs to the body (see Figure 6-33 on page 182 of your textbook). However, whereas the scapula has quite a bit of mobility over the thorax (you can demonstrate this by rolling your shoulder blades in a circle), the pelvic bones are firmly united to each other as well as to the sacrum, which is part of the vertebral column.

Picture the pelvis as a ring of bone that's open at the dorsal side, where the sacrum runs through it and firmly attaches to it to complete the ring of bone. The limbs attach to the pelvis at the ventral and lateral borders. The pelvis is comprised of right and left halves, each of which is called an *os coxae* (*os* = bone, *coxa* = hip). Each large os coxae forms during development from fusion of three separate bones: the ilium, ischium, and pubis. One of each of these bones is present on each side of the pelvis, but in the adult the bones are firmly fused and their boundaries are indistinguishable.

The *ilium* is the largest bone in the pelvis. It's a mostly flat, triangular bone that curves outward slightly at the cranial end, which is called the *wing.* The caudal part of the ilium is called the *body* (or *shaft*). The sacral part of the spine attaches firmly and closely to the medial side of the ilium by means of short and strong ligaments. The gluteal muscles of the pelvic limb attach to the lateral side of the ilium, which is called the *gluteal surface.*

The wing of the ilium widens near the cranial border like the base of a triangle. This area is called the *iliac crest*. The medial angle of the iliac crest is called the *tuber sacrale,* and the lateral angle is the *tuber coxae.* When veterinarians take bone marrow biopsies for diagnosis of bone marrow disease, the iliac crest's tuber sacrale is often the area biopsied.

The dorsal border of the body of the ilium is called the *greater ischiatic notch*. This area is important because the *sciatic nerve,* one of the major nerves of the pelvic limb, travels over it. Fractures of the ilium in this area can cause nerve damage, leading to paralysis of the pelvic limb.

Caudal and ventral to the ilium lies the *ischium,* which is also a mostly flat bone. The ischium's position is somewhat horizontal, whereas the ilium is positioned more vertically. The caudal and lateral angles of the ischium are known as the *ischiatic tuberosities.* The ischiatic tuberosities form a prominent angle of bone that you can palpate on either side of the tail of your dog. The ischium also serves as a point of attachment for several muscles of the hip, pelvic limb, and tail. The right and left ischium fuse with each other along the median plane on the ventral side of the pelvis to form the caudal part of the ventral floor of the pelvis.

The pubis bone lies cranial to the ischium on both sides of the pelvis. Like the right and left ischium, the right and left pubic bones fuse with each other along the median plane on the ventral side of the pelvis. These bones complete the floor, or ventral surface, of the pelvis. The seam where the right and left sides of the pelvis come together ventrally is called the pelvic *symphysis.* A firm plate of fibrocartilage unites the right and left sides of the pelvis at the pelvic symphysis. A large opening called the *obturator foramen* is formed by the ischium and pubis on each side of the pelvis. Nerves and blood vessels pass through this foramen to reach the inner thighs.

At the junction of the ilium, ischium, and pubis is a deeply concave joint surface called the *acetabulum.* This surface is where the femur articulates with the pelvis in a ball-and socket type joint that forms the hip. The pelvis is modified among various species in ways that reflect the habitat and method of locomotion of the animal. Also, because the pelvis forms a bony ring that becomes the birth canal in female animals, the pelvis of females is usually somewhat larger and rounder than that of males.

Femur

The *femur* is the thighbone. The femur is a long bone with a diaphysis and two epiphyses. The proximal end of the femur contains the head, which fits into the acetabulum to form the hip joint. The head of the femur is very round in species that have a lot of mobility in the hip joint, and flatter in species with less ability to rotate the hip and move it laterally. Just distal to the head, the femur narrows in an area known as the neck of the femur. This connects to the femur's body (or shaft). At the proximal end of the shaft are several projections called *trochanters* that serve as sites of attachment for various muscles, including the gluteals. The largest of these projections is the *greater trochanter,* which is located on the lateral side. The *lesser trochanter* lies on the medial side.

At the distal end of the femur are two curved surfaces that articulate with the tibia. These are called the *medial condyle* and the *lateral condyle.* Cranial and just proximal to the condyles lies a curved surface called the *trochlea,* where the *patella* (or kneecap) articulates. Just proximal and to the side of the condyles lie the *medial epicondyle* and *lateral epicondyle,* which are projections of bone above the condyles (*epi* = over) that attach the ligaments of the knee joint (see Figure 6-34 on page 183 of your textbook). The femur articulates distally with the tibia to form the *stifle joint* (i.e., the knee in humans). The femur anchors the muscles that bend the stifle joint and straighten the tarsal joint below.

Patella

The *patella* is the kneecap. It's the largest of the sesamoid bones in the body and is roughly oval-shaped, with a slight point on the distal end. The patella isn't directly connected to the femur. Instead, it's embedded in muscle tendons that straighten the knee joint, and it slides in the trochlea of the femur (i.e., the groove on the cranial and distal aspect of the femur) as these muscles contract and relax. The patella allows the tendons of the muscles of the leg's cranial surface to slide easily over the distal femur and improves the strength and leverage of the muscles that work across the stifle joint. This results in greater force being applied by these muscles as they extend the leg as well as greater speed for the animal. In addition to the patella, carnivores also have small sesamoid bones called *fabellae* that are located caudal to the distal femur.

Tibia and Fibula

The *tibia* and *fibula* are long bones that lie next to each other just distal to the femur (similar to the arrangement of the radius and ulna below the humerus in the foreleg). The tibia articulates with the femur to form the stifle joint. The tibia also attaches the muscles that bend the tarsal joint distally. The tibia is much larger than the fibula. If you cut the tibia in half perpendicular to its axis (i.e., a transverse section of the bone), it would look roughly triangular. The cranial aspect has a ridge called the tibial crest. At the proximal end of the *tibial crest* is a projection of bone called the *tibial tuberosity,* where ligaments connect the patella to the tibia. The proximal end of the tibia has two condyles—medial and lateral—that articulate with the femur's medial and lateral condyles. Between the condyles you find the *intercondylar eminence* (*inter* = between), the attachment site for some of the ligaments that connect the femur to the tibia.

The distal tibia articulates with the tarsal bones. On the medial side of the distal tibia is a bony projection known as the *medial malleolus,* which helps form the joint with the tarsal bones.

Connected to the tibia on its lateral side is a smaller bone, the fibula, which is long and thin. The *lateral malleolus* is a small process at the distal end of the fibula that articulates with the tarsal bones. The fibula is a completely separate bone in dogs and cats, but in horses, cows, sheep, and goats, the fibula is greatly reduced and is partially fused with the tibia, so there's no distinct body. In horses, the lateral malleolus is part of the tibia.

Tarsal Bones

The *tarsal bones* are a collection of bones that form the tarsus, which connects the tibia and fibula at the proximal end to the metatarsal bones at the distal end. In humans, the tarsal bones make up the heel and proximal part of the foot, but in most animals, these bones are off the ground in a standing animal. The tarsus is commonly referred to as the *hock joint* in large animals. The tarsus is similar to the carpus in the front limb. In domestic animals, you'll find five to seven tarsal bones, depending on the species, arranged in three rows. In the first row of tarsal bones are the talus and calcaneus.

The *calcaneus* is the largest tarsal bone and is equivalent to the bone that forms your heel. The calcaneus is a point for attachment of some of the muscles that straighten the tarsal joint. Medial to the calcaneus is the *talus,* which forms most of the joint with the tibia and fibula. The talus has a shape like a pulley—a central groove with two circular ridges on each side. The distal two rows of tarsal bones are variable between species.

As with the forelimb, the directional terms change slightly for structures distal to the tarsus. The upper surface of the metatarsals and digits is called the *dorsal surface;* the lower surface that faces or touches the ground is called the *plantar surface* (*plantar* refers to the sole of the foot).

Metatarsal Bones

The *metatarsal bones* are similar to the metacarpal bones in the thoracic limb. The differences among species in the number of bones and in which bones are reduced or absent are essentially the same as in the thoracic limb. Dogs and cats have five metatarsal bones per hind limb. Horses have a large third metatarsal bone called the cannon bone as well as small second and fourth metatarsal bones called *splint bones.*

Digits

The hind digits are very similar to the digits in the foreleg for each species. Review the material regarding the digits in the foreleg if you're unclear about the phalanges or sesamoid bones in the digits.

Birds, Reptiles, and Amphibians

The pelvic limb of birds is similar to mammals except that the distal portions of the pelvic bones aren't fused so that the pelvis can allow for passage of eggs. Most bird species contain four digits in the pelvic limb. In some species, the digits may not all face in the same direction. For example, the first and fourth toes of parrots are directed backward, while the second and third face forward. Most reptiles and amphibians have similar pelvic limb arrangements as mammals, although the size of the bones may differ.

Joints

Joints are the connections between bones. Joints help hold the bones together and give the skeleton flexibility and the ability to move. Joints are also shock absorbers that cushion some of the force when you walk or move. This cushioning keeps the force of movement from being transmitted directly to the bones, which are rigid and might break under the force.

The study of joints is sometimes called *arthrology* (*arthro* = joint). Joint names are based on the two bones being joined together. For example, the shoulder joint where the scapula and humerus articulate is called the *scapulohumeral joint.* The joint between the sacrum and ilium is the *sacroiliac joint.*

When two bones with the same name are joined, the prefix "inter-" is added to identify the joint. For example, a joint between two vertebrae is called an *intervertebral joint.* A specific intervertebral joint is then identified by the region and number of the vertebra on each side of that joint. For example, the junction of the third and fourth cervical vertebra is called the C3–C4 intervertebral joint. The joint between the last cervical and first thoracic vertebra is the C7–T1 intervertebral joint. Some joints have unique names based on layman's terms that are more commonly used than scientific names. For example, the knee joint in animals is technically the *femorotibial joint,* but it's more commonly called the *stifle joint.*

There are three types of joints:

1. *Synarthrosis*—A joint that allows no movement of the bones

   Synartroses are also referred to as *fibrous joints* since the bones are joined by fibrous tissue. Fibrous joints connect the bones of the skull to each other at wavy junctures known as *sutures.* Narrow regions of fibrous tissue unite the bones at the suture line. The splint bones in a horse are attached to the third metacarpal bone by a fibrous joint. Fibrous joints also connect the teeth to their bony sockets via a short, fibrous structure called a *periodontal ligament.*

2. *Amphiarthrosis*—A cartilaginous joint that allows only for slight rocking movement

   The intervertebral joints between the bodies of adjacent vertebrae are usually cartilaginous joints. Intervertebral disks made of fibrocartilage act as cushions and shock absorbers and allow the vertebrae to have some movement relative to each other.

3. *Diarthrosis*—A joint that allows a wide range of movement

   These joints are the most common type of joint found in the body. In a synovial joint, the articulating bones are separated by a fluid-filled space called a *joint cavity.* Synovial joints are found between most of the long bones in the body and have the greatest flexibility; that is, they're *diarthroses* (freely movable joints). Because of this need for movement, synovial joints have the most complex structure of all the joints.

Characteristics of Synovial Joints

On the articular surface of each bone in the joint is a thin layer of very smooth hyaline cartilage called *articular cartilage.* The articular cartilage has a spongy consistency that helps absorb shock, and its glassy smooth surface helps reduce friction (i.e., wear and tear) on the joint surface. The space between the articular cartilages of the two bones contains *synovial fluid,* which has a slippery consistency like egg whites and acts as a lubricant between the joint surfaces. In addition to lubricating the joint, synovial fluid also serves an important nutritive function. Hyaline cartilage has a very poor blood supply, and the synovial fluid serves to bring in oxygen and nutrients to the hyaline articular cartilage.

The lining of the joint cavity is called the *synovial membrane,* and it's composed of fibrous tissue, blood vessels, and cells that secrete the synovial fluid. The synovial membrane forms the inner layer of the *joint capsule,* which surrounds the joint. The outer layer of the joint capsule is called the *fibrous capsule,* which is composed of a fibrous layer that's continuous with the periosteum of the articulating bones.

Within some joints you'll find other structures as well. *Ligaments* are bands of fibrous connective tissue that connect one bone to another and help hold the bones in position. Some ligaments lie within the fibrous layer of the joint capsule. Some ligaments lie outside the joint capsule entirely, whereas others are located centrally in the joint. *Menisci* (singular, *meniscus*) are additional cartilage flaps that extend inward from the joint capsule in some joints (e.g., the stifle joint). Menisci add shock-absorbing ability and stability to joints under extra strain.

Synovial Joint Movements

Depending on the structure of a joint, various types of movement may be allowed. Descriptive terms for various sorts of movements can get quite complicated; we'll consider only the terms commonly used in veterinary practice here.

1. *Flexion* is a bending movement that decreases the angle between the two bones of the joint and brings them closer together.
2. *Extension* is the opposite of flexion. It's a movement that increases the angle between two bones and moves them farther apart.
3. *Abduction* is a movement at a joint that brings a body part away from the midline (think of abduction as "taking away").
4. *Adduction* is a movement that brings a body part toward the median plane.
5. *Rotation* is the movement of a long bone around its own long axis. This type of movement allows a pitcher to throw overhand. Bones that can rotate usually have a somewhat round articular surface proximally to allow this sort of movement. In dogs and cats, the humerus and femur have rounded heads with some ability to rotate in their respective joints. When taking radiographs of a dog to check for hip dysplasia, it's important to medially rotate the femurs (i.e., rotate the distal ends of the femur medially as much as possible) to get the best view of the hip joint.
6. *Circumduction* is the movement of an extremity so that the distal end moves in a circle. You can produce this movement by extending your arm and moving your hand in a circle.

Types of Synovial Joints

There are four basic types of synovial joints: hinge joints, gliding joints, pivot joints, and ball-and-socket joints.

1. *Hinge joints* are those in which one joint surface swivels around another. These joints are capable of only flexion and extension. The elbow joint is an example of a hinge joint.
2. *Gliding joints* are those that have flat surfaces that are capable of a rocking motion of one bone on the other. The carpus (see Figure 6-44 on page 189 of your textbook) is an example of a gliding joint. In most animals, this joint is capable of only flexion and extension.
3. *Pivot joints* are characterized by one bone rotating on another. The only true pivot joint in most animals is the *atlantoaxial joint* (see Figure 6-43 on page 189 of your textbook).
4. *Ball-and-socket joints* are capable of flexion, extension, abduction, adduction, rotation, and circumduction.

Before proceeding to the next assignment, take a moment to complete *Self-Check 6.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 6

1. The pelvic symphysis is an example of which type of joint?
   a. Amphiarthrosis
   b. Synovial joint
   c. Cartilaginous joint
   d. Diarthrosis

2. Which of the following is a deep ball-and-socket joint in dogs and cats?
   a. Elbow
   b. Stifle
   c. Hip
   d. Shoulder

(Continued)

Self-Check 6

3. Which joint has *menisci?*

   a. Hip
   b. Shoulder
   c. Elbow
   d. Stifle

4. Which structure within a synovial joint is continuous with the periosteum of the articulating bones?

   a. Hyaline cartilage
   b. Synovial membrane
   c. Fibrous capsule
   d. Meniscus

5. Oxygen and nutrients are primarily supplied to the hyaline cartilage on the articulating surfaces of a synovial joint by ________.

6. Movement at a joint that brings a limb away from the midline is called ________.

7. Movement at a joint that brings the long bones on either side of the joint closer together is called ________.

8. Digits that don't bear weight are called ________.

9. Three bones fuse to make up each half of the pelvis. The most cranial bone in the pelvis is the ________; the most caudal bone is the ________; the third bone, which lies ventrally, is the ________.

10. The three bones of the pelvis fuse together in a region called the ________, which articulates with the head of the femur.

Check your answers with those on page 189.

ASSIGNMENT 7: INTRODUCTION TO THE MUSCULAR SYSTEM

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 191–202, 427, and 477–478. Then read Assignment 7 in this study guide.

Muscle tissue performs several functions in the body; these functions vary with the location and type of muscle tissue involved. The most obvious function is to provide the force that moves your legs, arms, head, and other body parts. Most of the *voluntary muscles* (i.e., muscles under conscious control) work with bones to cause the bones to move at joints, much like levers. The point on the bone where the muscle attaches, the length of the bone, size of the muscle, and the flexibility of the joint each affect how the body moves when the muscle contracts.

Muscles also have other, less obvious functions. Nearly all of your blood vessels have a small amount of muscle tissue that encircles the vessel. When these muscle cells contract, the diameter of the vessel decreases. The constriction of the muscle in blood vessel walls decreases the amount of blood flow and increases the blood pressure in the vessel. Conversely, when the muscle relaxes, the diameter of the vessel increases, increasing blood flow and decreasing resistance to blood flow. These muscles allow the body to control blood pressure, heat loss, and blood flow to various areas.

In the digestive system, muscle contractions help to propel food from the mouth to the anus, mix food within the stomach and intestines, and retain food until it has been properly digested. In the urinary system, the muscles of the ureter wall propel urine to the bladder. Muscles in the bladder walls contract to empty the bladder. Muscles near the junction of the bladder and urethra keep urine from leaking out until the bladder is ready to void. Muscles in the reproductive system cause contractions of the uterus during labor in the female. Muscles in the ductus deferens carry sperm from the testes to the urethra in the male. The muscles between the ribs and the muscles of the diaphragm help expand the chest cavity so air can enter the lungs. Cardiac muscle tissue is responsible for contractions of the heart that result in blood flow. As is evident from this brief discussion, muscle tissue is vital to virtually all of the body's organ systems.

Types of Muscle Tissue

There are three types of muscle tissue in the body:

1. Skeletal or striated muscle
2. Smooth muscle
3. Cardiac muscle

(See Figure 7-1 and Table 7-1 on pages 192–193 of your textbook). The most abundant muscle tissue in the body is *skeletal muscle.* Skeletal muscle is also called *striated muscle* because under the microscope this muscle appears to have fine stripes crossing the muscle fibers at right angles. These stripes, or *striations,* are the result of the alignment and overlap of contractile fibers in the muscle tissue. Skeletal muscle is also called *voluntary muscle* because it's under voluntary control.

Smooth muscle may also be referred to as *visceral muscle.* It's found in the internal organs such as the bladder and blood vessels. Smooth muscle has contractile fibers in it like skeletal muscle, but the fibers don't appear as visible stripes under a microscope. Smooth muscle isn't under voluntary control; instead, involuntary nerves and hormones control its contractions. Thus, the term *involuntary muscle* is also used.

The final muscle type is *cardiac muscle,* which is found only in the heart. Cardiac muscle is also somewhat striated in appearance but isn't under voluntary control. Cardiac muscle is specialized to generate and conduct electrical impulses and undergo consistent rhythmic contractions.

Under microscopic examination, muscle tissue has unique properties that make it well suited to its function, which is to *contract* (i.e., shorten) to generate forces that move body parts. Let's examine each muscle type separately, because each type has unique features well suited for its specific location and purpose.

Skeletal Muscle Function

The body contains more than 450 skeletal muscles—far too many for you to learn the names and locations of all of them within the scope of this course. However, you should understand the principles of how muscles move the body and know the names and functions of some of the major skeletal muscles. This is important because some of the muscles are used as "landmarks" (i.e., reference points for injections and other procedures). Also, a basic familiarity with the names and locations of the important muscles help you communicate more professionally and precisely with the veterinarians you work with.

First of all, realize that muscles can exert forces on the body only by contracting. Therefore, muscles always move body parts by pulling—never by pushing. Most skeletal muscles either extend or flex a joint. Thus, many muscles are described as either *extensor muscles* or *flexor muscles*. To move in all available directions (e.g., flexion and extension), the muscles must be arranged in paired groups on opposite sides of the joint. These pairs oppose each other's actions, so that one group relaxes, whereas the other contracts. The *biceps brachii* flexes the elbow joint when it contracts, whereas the *triceps,* which lies along the caudal aspect of the humerus, extends the elbow by exerting its pull on the opposite side of the elbow joint (i.e., on the olecranon process of the ulna).

Sometimes a muscle can cause one joint to extend and another to flex. Depending on the action of other muscles within that limb, one or both joints move when the muscle contracts. For example, the *gastrocnemius* muscle is located in the calf area of your leg. When this muscle contracts with no opposition from other muscles, the knee joint bends and the tarsal joint extends. If other muscle groups opposing the gastrocnemius contracted at the same time, the knee joint might not bend, whereas the tarsus would still extend. You can see that the simple act of flexing your arm requires the contraction and relaxation of several muscles in a coordinated fashion.

Gross Anatomy of Skeletal Muscle

Muscles are groups of skeletal muscle cells surrounded by a layer of fibrous connective tissue. Muscles vary in shape and size, but most have a thick, central portion and two or more attachment sites, which join them to whatever they move when they contract. Muscles are usually attached to bones via tendons. *Tendons* are fibrous bands of connective tissue. A few muscles are attached to bones or other muscles via sheets of fibrous connective tissue called *aponeuroses.* The linea alba that attaches the abdominal muscles together in the ventral midline is an example of an aponeuroses. Note the distinction between a tendon, which connects a muscle to a bone, and a ligament (discussed earlier in this lesson), which connects one bone to another bone.

Muscle attachment sites are referred to as either the *origin* or the *insertion.* The site that exhibits the greatest motion when the muscle contracts is the insertion while the more stable site is the origin.

Muscle Groups

Let's briefly discuss some of the major muscle groups and some of the specific muscles in those groups, starting with the thoracic limb. In the shoulder, the *supraspinatus* muscle, cranial to the spine of the scapula, is an extensor muscle of the shoulder joint. Other muscles that attach the humerus to the neck and spine aid the supraspinatus in straightening the shoulder. The *infraspinatus* muscle, caudal to the scapular spine, flexes the shoulder joint in conjunction with muscles that attach the humerus to the spine or sternum.

The *pectoral muscles* along the ventral chest adduct the leg (i.e., pull it medially) by attaching the humerus to the sternum, whereas other muscles, such as the *trapezius* muscle, abduct the leg (i.e., pull it laterally) or pull it dorsally by attaching the scapular spine to the dorsal spine.

The *biceps brachii* muscle lies on the anterior surface of the humerus, attaches the distal scapula to the radius, and causes the shoulder to extend and/or the elbow to flex. The biceps muscle is the large muscle on your upper arm that can be seen when you bend your elbow.

On the caudal surface of the humerus is the *triceps* muscle, which opposes the biceps muscle. The triceps originates on the caudal edge of the scapula and proximal humerus and ends at the olecranon of the ulna. When the triceps muscle contracts, the shoulder flexes and the elbow extends.

On the anterior surface of the radius and ulna are a variety of muscles that flex the elbow joint, extend the carpal joint, and/or extend the digits. Opposing these muscles along the palmar surface of your forearm are muscles that flex the carpal joint or digits and/or extend the elbow joint. The arrangement and names of these muscles are too complicated and vary too widely between animal species (because the arrangement of digits varies widely as well) to cover in this course.

In the hind limb, several *gluteal muscles* lie on the lateral surface of the hip and act primarily to abduct the limb. However, these gluteal muscles also extend the hip joint (i.e., pull the leg back). These muscles originate on the pelvic bones and end at the proximal femur, making up much of the buttocks region. The gluteals are counteracted by several muscles on the medial surface of the thigh that adduct the leg; these muscles originate on the ventral-lateral pelvis and attach to the medial femur.

The biceps femoris muscle, the semitendinosus muscle, and the semimembranosus muscle all lie on the caudal surface of the femur and are collectively called the *hamstrings*. These muscles attach to the caudal aspects of the pelvis and to the tibia and calcaneus. When these muscles contract, the hip joint extends, the knee flexes, and the ankle extends. On the anterior surface of the femur is the *quadriceps femoris* muscle, which opposes the hamstring muscles. The quadriceps is the large muscle on the front of the thigh. Contraction of the quadriceps extends the knee joint and flexes the hip joint.

The anterior surface of the tibia is covered with several muscles that cause the knee to extend, the ankle to bend, and the digits to extend. Opposing these muscles are the *gastrocnemius* muscle as well as other muscles that flex the knee, extend the tarsal joint, and flex the digits—much like the muscles in the distal part of the thoracic limb.

Traveling alongside and attaching to the vertebrae are several muscles that flex and extend the spine or allow the spine to turn side to side. These muscles are too numerous to describe in detail here. Muscles connecting the neck and head to the shoulder and thoracic limbs pull the thoracic limbs forward or flex the neck and bring the head down. The muscles along the dorsal neck and spine help pull the head up. A variety of muscles in the head are responsible for facial expression, chewing, and movements of the eyes and ears; again, these are too numerous to examine in detail at this level.

Between the ribs are intercostal muscles that aid in breathing, as do the muscles that connect the ribs to the spine. Both are aided by the diaphragm, the muscle that separates the thorax and abdomen.

Major Muscles of the Thoracic Limb in the Dog

The origins and insertions of these muscles are listed here to help you understand the locations and actions of the muscles. You do need to be familiar with the location and action of each of the major muscle groups.

- Supraspinatus muscle

  Origin: supraspinous fossa of scapula

  Insertion: greater tubercle of humerus

  Action: extends shoulder

- Infraspinatus muscle

  Origin: infraspinous fossa of the scapula

  Insertion: proximal humerus

  Action: flexes the shoulder joint

- Pectoral muscles

  Origin: sternum

  Insertion: proximal humerus

  Action: adducts the leg (i.e., pulls it medially)

- Trapezius muscle

  Origin: structures, ligaments along dorsal midline

  Insertion: spine of scapula

  Action: abducts the leg (i.e., pulls it laterally) and elevates it

- Biceps brachii

  Origin: supraglenoid tubercle of scapula

  Insertion: Proximal radius and ulna

  Action: flexes elbow, extends shoulder (the biceps muscle is the large muscle on your upper arm that becomes firm when you flex your elbow)

- Brachialis

  Origin: proximal lateral surface of humerus

  Insertion: proximal radius and ulna

  Action: flexes elbow

- Triceps brachii

  Origin: three heads (regions) that originate from proximal humerus, scapula

  Insertion: olecranon process of ulna

  Action: extends elbow

Major Muscles of the Pelvic Limb in the Dog

- Gluteal muscles—superficial, middle, and deep

  Origin: various points on sacrum and pelvic bones

Insertion: greater trochanter of the femur (and third trochanter)

Action: to extend and abduct the hip

- Biceps femoris

  Origin: ischiatic tuberosity

  Insertion: attaches to *fascia lata* (i.e., sheet of connective tissue) cranially and to calcaneus by means of common calcanean tendon

  Action: extends hip, stifle, and tarsus

- Semitendinosus

  Origin: ischiatic tuberosity

  Insertion: tibia and calcaneus

  Action: extends hip, flexes stifle, extends tarsus

- Semimembranosus

  Origin: ischiatic tuberosity

  Insertion: distal femur and medial condyle of tibia

  Action: extends hip

- Quadriceps femoris—made up of four muscles: rectus femoris, vastus lateralis, vastus intermedius, and vastus medialis, which fuse distally to form one tendon of the quadriceps in which the patella is embedded

  Origin: proximal femur and ilium

  Insertion: tibial tuberosity, via patellar ligament

  Action: powerful extensor of the stifle, also flexes hip

- Cranial tibial muscles (cranial tibial, peroneus longus, digital extensors)

  Origin: cranial lateral

  Insertion: tarsals, metatarsals, and phalanges

  Action: flex tarsus, extend digits

- Gastrocnemius—forms main component of common calcanean tendon (Achilles tendon)

  Origin: distal femur

  Insertion: calcaneus via calcanean tendon

  Action: primarily extends tarsus, also flexes stifle

On the cranial and lateral surface of the radius and ulna are a variety of muscles that extend the carpal joint and/or extend the digits. Feel these muscles contract as you extend your own wrist and fingers. Opposing these muscles along the caudal and medial surface of the forearm are muscles that flex the carpal joint or digits. Feel them as well in your own arm. The specific arrangement and names of these muscles are too complicated and vary too widely between species (especially because the arrangement of digits varies widely as well) to justify covering them in this course.

Birds, Reptiles, and Amphibians

Avian skeletal muscles have either white or red muscle fibers or both. *White muscle fibers* are thick in diameter and use stores of glycogen to sustain muscle contraction. Flight muscles of short-distance fliers (i.e., chickens) consist primarily of white muscle fibers. *Red muscle fibers* are thinner and have a rich supply of blood, fat, myoglobin, and mitochondria. This type of muscle fiber predominates in birds that fly long distances (i.e., water birds, hawks). Many of the muscle group pairings seen in mammals are also present in birds. Adaptations such as larger pectoral muscles allow for the unique needs of flight. In perching species, adaptations of the muscles over the femur are also present. Muscles of the head and neck show adaptation based on the type of food consumed. Species that consume large seeds and nuts have larger, stronger jaw muscles than those that consume insects or small seeds.

Snakes have unique muscular arrangements that allow for a variety of unique movements (see Figure 20-33 on page 477 of your textbook). Muscle structure and function of most other reptile and amphibian species is similar to that seen in mammals. However, most amphibian and reptile species can't sustain prolonged physical activity due to the higher reliance on anaerobic respiration within their muscle cells.

Skeletal Muscle Structure

Three connective tissue layers are associated with skeletal muscle. The outer fibrous layer that covers entire skeletal muscles is called the *epimysium.* The *endomysium* is a thin connective tissue layer that covers individual skeletal muscle fibers. The *perimysium* binds together groups of skeletal muscle, called *fascicles.* The three connective tissue layers help fasten the muscle to tendons or aponeuroses.

Each muscle fiber is a single cell, but muscle cells are unusual in that each muscle cell is a very long, thin cell that contains many nuclei placed on the cell's outer edge at intervals along the cell's length. These cells have multiple nuclei because during fetal development they're formed from the fusion of several cells, each with one nucleus. When muscle tissue grows as an animal gets bigger or builds muscle tissue through exercise, the skeletal muscle tissue grows by enlargement of the muscle fibers (the cells gain more contractile proteins) rather than through an increase in the number of cells.

The structure of muscle cells is like that of other cells, but the specialization of these structures within muscle cells has led to unique names for some of them. The cell membrane is called the *sarcolemma;* the cytoplasm is called the *sarcoplasm;* the endoplasmic reticulum is called the *sarcoplasmic reticulum;* and the mitochondria are called *sarcosomes.* As is probably evident from these terms, the prefix "sarco" always refers to muscle.

Each skeletal muscle fiber cell is packed with smaller cylindrical structures called *myofibrils* that run the length of the cell in parallel fashion. Myofibrils appear to have bands (i.e., striations) across them; these striations are the result of the arrangement of the contractile protein fibers within the myofibril. The myofibrils contain thick filaments composed of a protein molecule called *myosin,* and thin filaments, composed of a protein molecule called *actin.* These filaments are highly organized within the myofibril, and the visible difference in the regions of thick filaments, thin filaments, and areas of overlap between the two creates the striations visible in skeletal muscle under the microscope. The tubules of the sarcoplasmic reticulum encircle each myofibril like a sleeve with holes in it.

The thick myosin filaments are arranged in bundles like a stack of toothpicks with a little space between each and are referred to as the "A band." The thin actin filaments are bundled together in the same fashion and are referred to as the "I band." The two bundles *interdigitate;* that is, they fit together like your fingers when you clasp your hands together. In the center of the "I band" is a dark line called the "Z line." The Z line contains specialized proteins and provides the site where the actin filaments attach. The area from one Z line to the next Z line is called a *sarcomere* and is the basic contracting unit of skeletal muscle. Each myofibril is made up of many sarcomeres lined up end to end. As you'll see, when the muscle contracts, the thick and thin filaments slide over each other, with the thick filaments filling in the space between the thin filaments and vice versa.

The muscle cell membrane, the sarcolemma, folds inward in several locations, giving rise to a network of communication tubules called the *T-tubules.* The T-tubules intertwine with the myofibrils throughout the cell and enable the muscle cell to transmit the contraction signal to all of the myofibrils in the cell at the same time.

A separate network of tubules called the *sarcoplasmic reticulum*—derived from smooth endoplasmic reticulum—also fills the space between the myofibrils. The sarcoplasmic reticulum stores calcium inside its tubules while the muscle fibers are at rest (i.e., not contracting).

Skeletal muscle myofibrils have their thin actin filaments arranged side by side in a cylinder and partly interdigitating with thick myosin filaments. Each myosin filament has many heads, or *cross bridges,* consisting of pieces of protein that stick out from the core of the filament and reach toward the actin molecules. These cross bridges are important because they link the thick myosin filaments to active sites on the thin actin filaments when the muscle contracts.

Muscle Contraction

Skeletal muscle must be signaled to contract by the nervous system. Individual muscle fibers either contract completely when stimulated or they don't contract at all. This is known as the *all-or-nothing principle.* Contraction of a muscle fiber proceeds in three phases that take a total of about 0.1 second. Timing of impulses from the nervous system to the motor units of the muscle results in slight variation in the initiation of the contraction impulses to the muscle so that they're occurring at slightly different times. This allows for smooth sustained muscle contraction.

Muscle fibers are associated with motor nerve fibers in locations referred to as *neuromuscular junctions.* The term *motor unit* represents a nerve fiber and the muscle fibers with which it interacts. A single nerve fiber interacts with multiple muscle fibers. The neuromuscular junction is actually a small space (the *synaptic space*) between a nerve fiber and the sarcolemma of the muscle fibers. The neurotransmitter chemical, *acetylcholine,* diffuses across this space from the nerve fiber and attaches to receptors on the sarcolemma. This initiates a series of events that lead to contraction of the muscle. The nervous system controls the timing of this impulse generation as well as the number of motor units that are stimulated.

Binding of acetylocholine to these receptors generates an electrical impulse along the sarcolemma. The excitatory signal is carried inside the muscle cell by the T-tubule system, which contacts all of the myofibrils in the cell. Electrical changes in the T-tubules cause reach the sarcoplasmic reticulum and cause it to release its stored calcium ions. This Ca++ diffuses into the myofibrils. The presence of an increased concentration of calcium causes the cross bridges on the myosin filaments to slide back and forth. That motion causes the actin filaments to be pulled toward the center of the myosin filaments and results in the shortening of the sarcomere. The muscle contracts when all of the sarcomeres in a muscle fiber have shortened. These movements require substantial amounts of ATP. ATP must bind to the myosin head before the contraction begins. The myosin head splits the ATP into ADP and phosphate.

Skeletal Muscle Relaxation

The electrical current stops flowing through the sarcolemma and the T-tubules as soon as the stimulus from the nerve fiber ends. Calcium is then drawn out of the myofibrils and back into the sarcoplasmic reticulum. The reduced calcium level within the myofibril interrupts the binding of actin and myosin, and the entire muscle lengthens back into its original position again as the muscle relaxes. Pumping the Ca++ back into the sarcoplasmic reticulum also requires energy in the form of ATP.

Muscle Metabolism

As muscles use up ATP to provide energy for contraction and relaxation, more ATP must be generated by the cell. The way in which cells generate more ATP depends in large part upon whether oxygen is readily available in sufficient amounts. If oxygen is readily available, muscle cells generate ATP by aerobic respiration. However, if the muscles are contracting so vigorously that oxygen is being depleted and the aerobic pathway can't keep up with the need for ATP, the muscles switch over to a process of generating ATP that doesn't require oxygen—*glycolysis.*

The advantage of anaerobic glycolysis is that this process can be used during periods of extreme muscular exertion when oxygen availability is limited. Glycolysis can generate ATP faster than aerobic respiration, which requires many chemical steps in the mitochondria. However, the disadvantages of the anaerobic pathway are that (1) it generates only two molecules of ATP per molecule of glucose and (2) it leads to the accumulation of *lactic acid* within the muscle. Lactic acid, in large amounts, contributes to muscle fatigue and muscle soreness that occurs after extreme exertion. After the muscular activity has ended, the lactic acid moves out of the muscle cells into the bloodstream and is picked up by liver cells, which then metabolize it.

Muscle fibers contain another compound, *creatine phosphate (CP),* that's involved in the resupply of ATP molecules. CP anaerobically generates ATP from ADP, resulting in the formation of *creatinine.* The reaction requires the enzyme creatine kinase and results in the “donation” of a phosphate group to an ADP molecule, forming ATP.

The production of ATP and CP requires both glucose and oxygen. Muscles have well developed vasculature that transports glucose and oxygen to the muscle fibers. Glucose and oxygen can also be stored in the muscle. Muscle fibers store glucose in the form of glycogen, and oxygen within the myoglobin molecule.

Before proceeding to the next assignment, take a moment to complete *Self-Check 7.* Remember, you can check your answers by turning to the back of this study guide.

Self-Check 7

Questions 1–5: Match the following terms with their definitions below by placing the letter of the best definition in the blank space next to each term.

_______ 1. Myosin

_______ 2. T-tubule

_______ 3. Actin

_______ 4. Biceps brachii

_______ 5. Triceps

a. Muscle that flexes the elbow

b. Muscle that extends the elbow

c. Transmits contractile signals to the myofibrils

d. Thick-filament protein

e. Thin-filament protein

(Continued)

Self-Check 7

6. Name the three main types of muscle.

____

____

____

7. For each of the three types of muscle you've just listed, state whether each is under voluntary or involuntary control.

____

____

____

8. The neurotransmitter responsible for the initiation of muscle contraction is ________.

9. The area from one Z line to the next Z line is called a _________.

10. When muscle groups must rely on anaerobic respiration, ________ accumulates in the muscle and can lead to muscle fatigue and soreness.

Check your answers with those on page 189.

ASSIGNMENT 8: MUSCLE FUNCTION

Read in your textbook, *Clinical Anatomy and Physiology for Veterinary Technicians,* pages 202–204. Then read Assignment 8 in this study guide.

Cardiac-Muscle Function

Cardiac muscle is found only in the heart, and it's different from smooth muscle and skeletal muscle in several ways.

Cardiac muscle cells are much smaller than skeletal muscle cells and aren't organized into distinct groups. Cardiac muscle fibers are long and thin. They branch, intertwine, and fuse with each other almost like a woven basket. Also unique to cardiac muscle are structures called *intercalated disks,* which connect adjacent cardiac muscle cells and have a low resistance to electrical current. Intercalated disks help transmit electrical impulses for contractions from cell to cell. Cardiac muscle cells are so closely bound, and the excitation signal so easily transmitted from one cell to another, that when one cell is excited, nearly all the other cells become excited as well. Thus, cardiac muscle functions almost like one large muscle fiber.

Cardiac muscle cells are capable of contraction without any external stimulus, and when grouped together, the cells will contract at the same rate as the cell in the group with the most rapid rate.

Each heartbeat begins when and impulse is generated at the *sinoatrial (SA) node* located in the wall of the right atrium. This impulse then travels through muscle fibers called *Purkinje fibers* that serve as the conduction system of the heart.

Nerve fibers that innervate the heart originate from both the sympathetic and parasympathetic divisions of the nervous system. These two systems have opposite effects. The fibers from the sympathetic system stimulate the heart to beat harder and faster, while those of the parasympathetic system cause the heart to beat more slowly and with less force.

Cardiac muscle lies somewhere between striated and smooth muscle in its function and organization. Like smooth muscle, cardiac muscle is controlled by the involuntary nervous system. However, like skeletal muscle, cardiac muscle has visible striations created by the highly ordered arrangement of the actin and myosin myofilaments within the myofibrils. Like smooth muscle, cardiac muscle undergoes rhythmic contractions and contains only one nucleus (sometimes two) per muscle cell. The nucleus is centrally located. Cardiac muscle has a greater concentration of sarcosomes (i.e., mitochondria) than skeletal muscle, because it has a greater need for energy on a continuous basis than does skeletal muscle.

It's important to remember that the following substances are vital at the microscopic level to maintaining normal muscle function.

- Calcium is extremely vital to muscle function. Abnormally low or high levels of calcium can interfere with normal muscle contraction, which is especially serious in the heart.
- Potassium, sodium, and chloride are also very important. These three ions control the electrical charge present on the muscle cell membrane, both when the muscle is at rest and during the excitation process. The movement of these ions across the sarcolemma can affect the speed, duration, and strength of the muscle contraction. Again, a deficiency or excess of these ions can halt the normal excitation-contraction process.
- ATP is extremely important because it provides the energy for contraction. Anything interfering with the synthesis of ATP in the sarcosomes lead to paralysis, because no energy will be available for contraction. (Of course, ATP is important in all cells, because many cell operations require energy provided by ATP.)
- Finally, protein is necessary because the contraction mechanism is composed of proteins. Although all tissue in the body has some degree of protein, muscle tissue has the highest protein concentration of all body tissues.

Smooth-Muscle Function

Two forms of smooth muscle are found in the body. *Visceral smooth muscle* is located in the walls of hollow organs in the body, such as the digestive tract, urinary tract, respiratory tract, and blood vessels. *Multiunit smooth muscle* is found in small groups in places such as the lens of the eye.

Contraction of smooth muscle isn't under voluntary control. Smooth muscle cells are much smaller than skeletal muscle fibers and have only one central nucleus per cell. Like skeletal muscle, smooth muscle does have overlapping actin and myosin filaments, with contraction involving the filaments sliding past each other. However, the actin and myosin aren't as highly organized as they are in skeletal muscle, which is why smooth muscle doesn't look striated under the microscope.

Smooth muscle contraction is similar to skeletal muscle contraction, but with the following important differences:

- Smooth-muscle cells are capable of contracting without external stimulus but do react to stretching of the muscle. In the gastrointestinal tract, the stretching results in stronger contraction.
- Most smooth-muscle cells are connected to nerves of the autonomic, or involuntary, nervous system rather than to voluntary nerves.
- Smooth-muscle fibers are generally shorter than skeletal muscle, but the smooth-muscle cells can contract more relative to their size compared with skeletal muscle.
- The conduction of the excitation signal differs because no T-tubules are found in smooth muscle, and only a poorly developed sarcoplasmic reticulum exists. The process of calcium release in response to an excitation signal is slow compared with that in skeletal muscle.
- Smooth-muscle cells have the ability to transmit electrical stimulation from cell to cell, allowing a sheet of smooth-muscle cells to respond together.
- Some smooth-muscle cells are stimulated or inhibited by hormones rather than (or in addition to) being stimulated by nerve endings. Contraction of smooth-muscle cells may be stimulated and maintained by hormones that signal the smooth-muscle cells to remain in an almost indefinite state of contraction (e.g., the sphincters in the digestive system are contracted most of the time).
- Smooth muscle undergoes continuous, rhythmic, relatively low-force contractions as a unit instead of the intermittent, sharply defined, higher-strength contractions of skeletal muscle.

Peristalsis

As stated earlier, sheets of smooth-muscle cells often appear in the walls of hollow organs like the urinary, reproductive, and digestive tracts. Usually, tubelike organs such as the intestine have at least two layers of smooth muscle present. One layer has the cells oriented lengthwise along the tube *(longitudinal muscle),* and the other layer has the muscle cells oriented perpendicular to the first in a circular orientation around the circumference of the tube (i.e., *circular muscle*). The two layers contract alternately. When the circular muscle contracts, the tube lengthens and decreases in diameter in that region; when the longitudinal layer of muscle contracts, the tube shortens. Rhythmic, wavelike contractions of these two layers serve to move the contents down the length of the tube. This process is called *peristalsis.*

Multiunit Smooth Muscle

Multiunit smooth muscle is small and delicate. It's composed of individual smooth-muscle cells or small groups of cells and is found where small, delicate contractions are needed. These locations include the iris and ciliary body of the eye, the walls of small blood vessels, and around small air passageways in the lungs. Contractions of multiunit smooth muscle require specific impulses from the nervous system to contract.

Review the material you've learned in this study guide as well as the assigned pages in your textbook for Assignments 4–8. Once you feel you understand the material, complete *Self-Check 8.* Then check your answers with those provided at the end of this study guide. If you've missed any answers, or you feel unsure of the material, review the assigned pages in your textbook and this study guide. When you're sure that you completely understand the information presented in Assignments 4–8, complete your examination for Lesson 2.

Self-Check 8

1. *True or False?* Stretching of the smooth muscle in the walls of the uterus causes more forceful contractions.

2. *True or False?* All smooth muscle can contract without external stimuli.

3. *True or False?* Smooth-muscle cells don't contain T-tubules.

4. Rhythmic contraction of smooth muscle is referred to as _______.

5. The two types of smooth muscle are _______ and _______.

Check your answers with those on page 189.