5

The Skeletal System

FUNCTION PREVIEW

- The skeletal system provides an internal framework for the body, protects organs by enclosure, and anchors skeletal muscles so that muscle contraction can cause movement.

Although the word skeleton comes from the Greek word meaning "dried-up body," our internal framework is so beautifully designed and engineered that it puts any modern skyscraper to shame. Strong, yet light, it is perfectly adapted for its functions of body protection and motion. No other animal has such relatively long legs (compared to the arms or forelimbs) or such a strange foot, and few have such remarkable grasping hands. Even though the infant's backbone is like an arch, it soon changes to the swayback, or S-shaped, structure that is required for the upright posture.

The skeleton is subdivided into two divisions: the **axial skeleton,** the bones that form the longitudinal axis of the body, and the **appendicular skeleton,** the bones of the limbs and girdles. In addition to bones, the **skeletal system** includes *joints, cartilages,* and *ligaments* (fibrous cords that bind the bones together at joints). The joints give the body flexibility and allow movement to occur.

Bones: An Overview

- ✓ Identify the subdivisions of the skeleton as axial or appendicular.
- ✓ List at least three functions of the skeletal system.
- ✓ Name the four main classifications of bones.

At one time or another, all of us have heard the expressions "bone tired," "dry as a bone," or "bag of bones"—pretty unflattering and inaccurate images of some of our most phenomenal organs. Our brains, not our bones, convey feelings of fatigue, and bones are far from dry. As for "bag of bones," they are indeed more obvious in some of us, but without bones to form our internal skeleton, we would creep along the ground like slugs, lacking any definite shape or form. Let's examine how our bones contribute to overall body homeostasis.

Functions of the Bones

Besides contributing to body shape and form, our bones perform several important body functions:

1. **Support.** Bones, the "steel girders" and "reinforced concrete" of the body, form the internal framework that supports the body and cradles its soft organs. The bones of the legs act as pillars to support the body trunk when we stand, and the rib cage supports the thoracic wall.
2. **Protection.** Bones protect soft body organs. For example, the fused bones of the skull provide a snug enclosure for the brain, allowing someone to head a soccer ball without worrying about injuring the brain. The vertebrae surround the spinal cord, and the rib cage helps protect the vital organs of the thorax.
3. **Movement.** Skeletal muscles, attached to bones by tendons, use the bones as levers to move the body and its parts. As a result, we can walk, swim, throw a ball, and breathe. Before continuing, take a moment to imagine that your bones have turned to putty. What if you were running when this change took place? Now imagine your bones forming a rigid metal framework inside your body, somewhat like a system of plumbing pipes. What problems could you envision with this arrangement? These images should help you understand how well our skeletal system provides support and protection while allowing movement.
4. **Storage.** Fat is stored in the internal (marrow) cavities of bones. Bone itself serves as a storehouse for minerals, the most important of which are calcium and phosphorus. Most of the body's calcium is deposited in the bones as calcium salts, but a small amount of calcium in its ion form (Ca^{2+}) must be present in the blood at all times for the nervous system to transmit messages, for muscles to contract, and for blood to clot. Problems occur not only when there is too little calcium in the blood, but also when there is too much. Hormones control the movement of calcium to and from the bones and blood according to the needs of the body. Indeed, "deposits" and "withdrawals" of calcium (and other minerals) to and from bones go on almost all the time.
5. **Blood cell formation.** Blood cell formation, or hematopoiesis (hem″ah-to-poi-e′sis), occurs within the marrow cavities of certain bones.

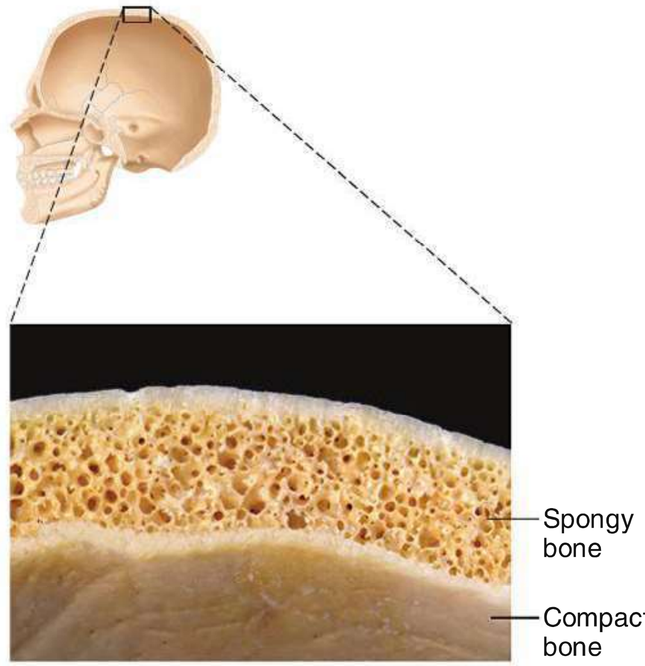


Figure 5.1 **Flat bones consist of a layer of spongy bone sandwiched between two thin layers of compact bone.**

Classification of Bones

The adult skeleton is composed of 206 bones. There are two basic types of osseous, or bone, tissue: **Compact bone** is dense and looks smooth and homogeneous (**Figure 5.1**). **Spongy bone** is composed of small needlelike pieces of bone and lots of open space.

Additionally, bones come in many sizes and shapes. For example, the tiny pisiform bone of the wrist is the size and shape of a pea, whereas the femur, or thigh bone, is nearly 2 feet long and has a large, ball-shaped head. The unique shape of each bone fulfills a particular need. Bones are classified according to shape into four groups: long, short, flat, and irregular (**Figure 5.2**).

As their name suggests, **long bones** are typically longer than they are wide. As a rule they have a shaft with heads at both ends. Long bones

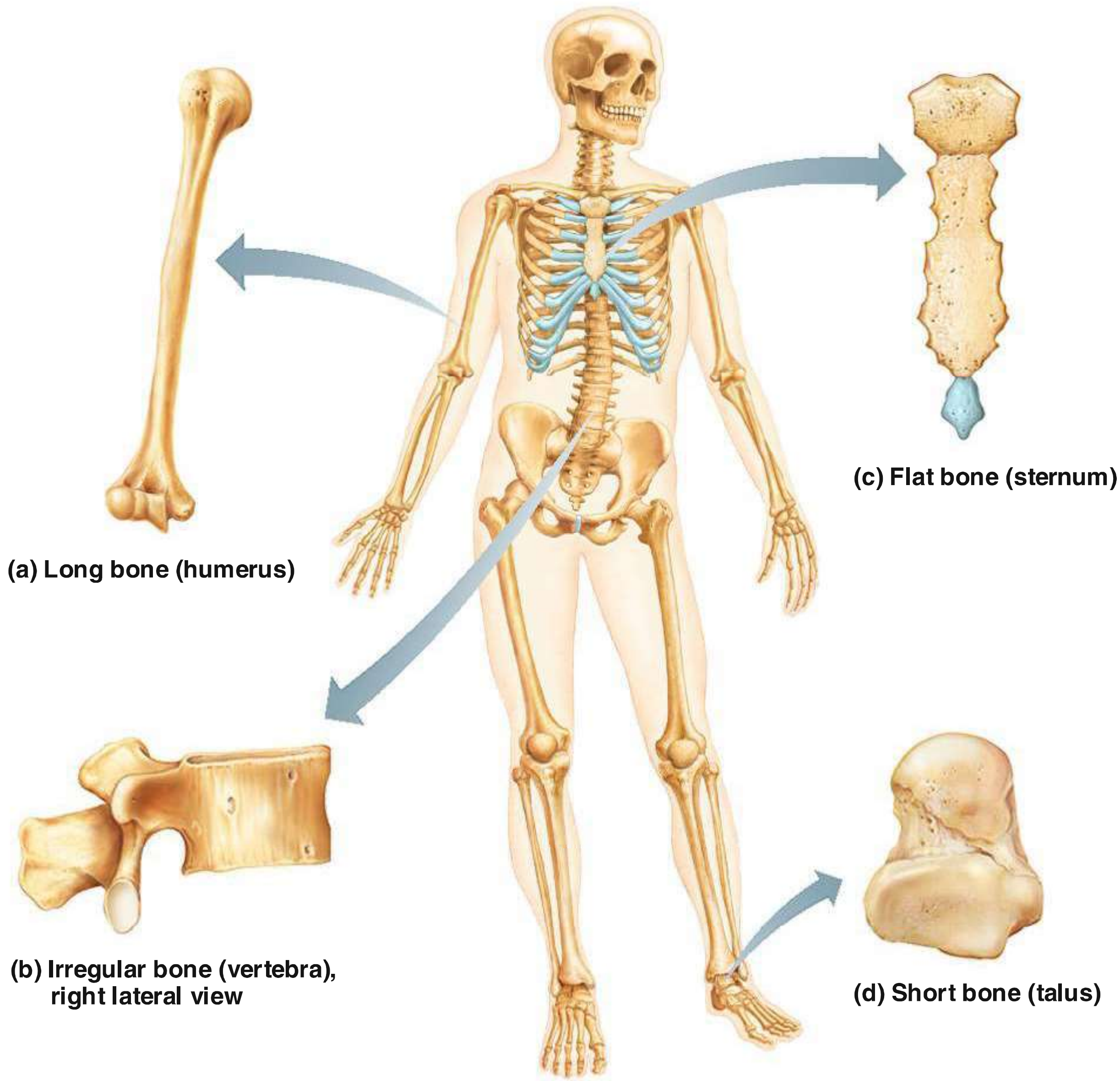


Figure 5.2 **Classification of bones on the basis of shape.**

are mostly compact bone. All the bones of the limbs, except the patella (kneecap) and the wrist and ankle bones, are long bones.

Short bones are generally cube-shaped and contain mostly spongy bone. The bones of the wrist and ankle are short bones. *Sesamoid* (ses′ah-moyd) *bones,* which form within tendons, are a special type of short bone. The best-known example is the patella.

Flat bones are thin, flattened, and usually curved. They have two thin layers of compact bone sandwiching a layer of spongy bone between them (see Figure 5.1). Most bones of the skull, the ribs, and the sternum (breastbone) are flat bones.

Bones that do not fit one of the preceding categories are called **irregular bones.** The vertebrae, which make up the spinal column, and the hip bones fall into this group.

DID YOU GET IT?

1. What is the relationship between muscle function and bones?
2. What are two functions of a bone's marrow cavities?
3. Where are most long bones found in the body?

For answers, see Appendix D.

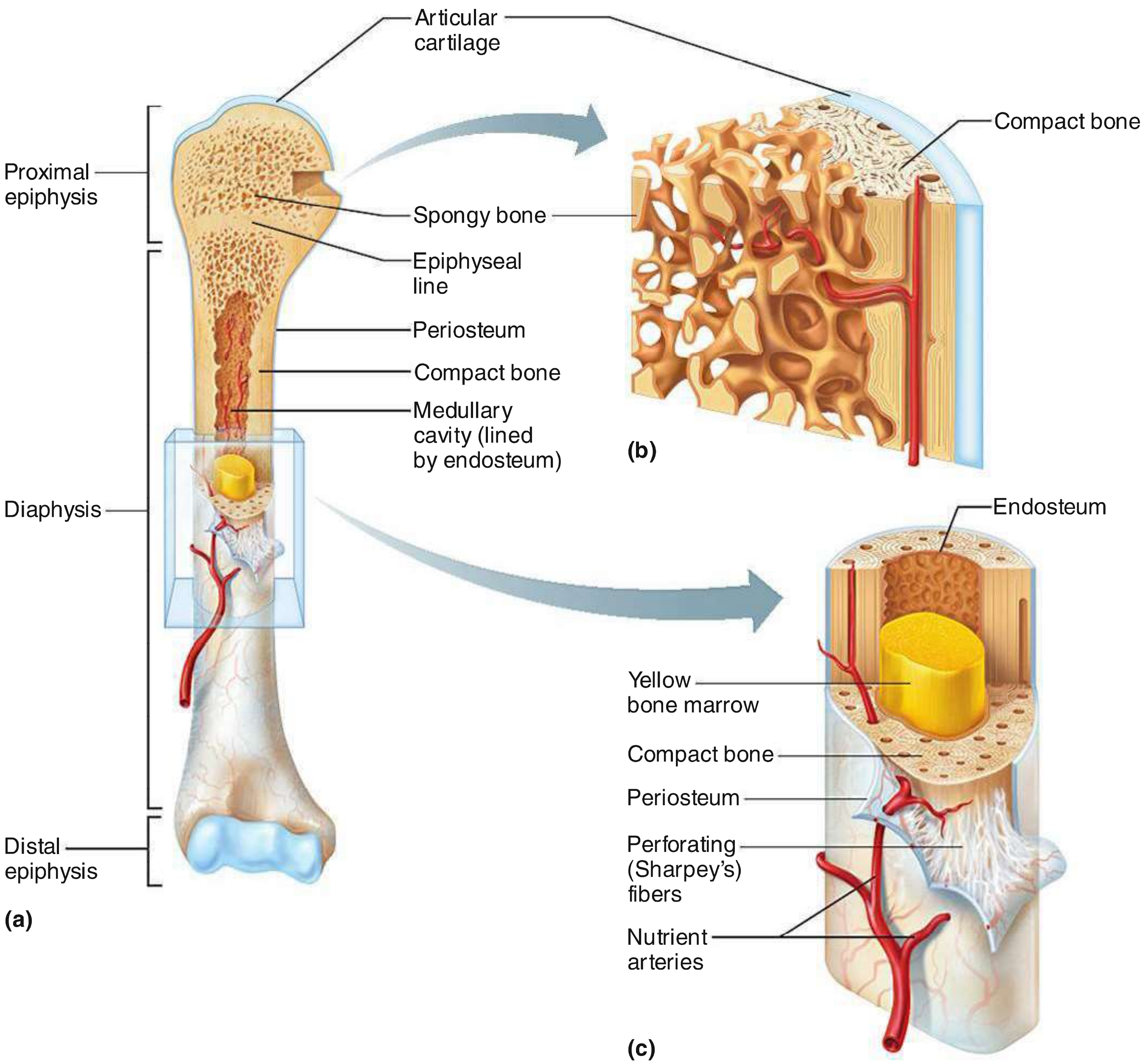


Figure 5.3 The structure of a long bone (humerus of arm). **(a)** Anterior view with longitudinal section cut away at the proximal end. **(b)** Pie-shaped, three-dimensional view of spongy bone and compact bone of the epiphysis. **(c)** Cross section of the shaft (diaphysis). Note that the external surface of the diaphysis is covered by a periosteum, but the articular surface of the epiphysis (see a and b) is covered with hyaline cartilage.

Structure of Bone

- ✓ Identify the major anatomical areas of a long bone.
- ✓ Describe the microscopic structure of compact bone.
- ✓ Explain the role of bone salts and the organic matrix in making bone both hard and flexible.

Gross Anatomy of a Long Bone

The gross structure of a long bone is shown in Figure 5.3. The **diaphysis** (di-af′ĭ-sis), or shaft, makes up most of the bone's length and is composed of compact bone. The diaphysis is covered and protected by a fibrous connective tissue membrane, the **periosteum** (per-e-ŏs′te-um). Hundreds of connective tissue fibers, called **perforating,** or **Sharpey's, fibers** secure the periosteum to the underlying bone.

The **epiphyses** (ĕ-pif′ĭ-sēz) are the ends of the long bone. Each epiphysis consists of a thin layer of compact bone enclosing an area filled with spongy bone. **Articular cartilage,** instead of a periosteum, covers its external surface. Because the articular cartilage is glassy hyaline cartilage, it provides a smooth, slippery surface that decreases friction at joint surfaces.

In adult bones, there is a thin line of bony tissue spanning the epiphysis that looks a bit different from the rest of the bone in that area. This is the **epiphyseal line.** The epiphyseal line is a remnant of the **epiphyseal plate** (a flat plate of hyaline cartilage) seen in a young, growing bone. Epiphyseal plates cause the lengthwise growth of a long bone. By the end of puberty, when hormones inhibit long bone growth, epiphyseal plates have been completely replaced by bone, leaving only the epiphyseal lines to mark their previous location.

In adults the cavity of the shaft is primarily a storage area for adipose (fat) tissue. It is called the **yellow marrow,** or **medullary, cavity.** However, in infants this area forms blood cells, and **red marrow** is found there. In adult bones, red marrow is confined to cavities in the spongy bone of flat bones and the epiphyses of some long bones.

Even when looking casually at bones, you can see that their surfaces are not smooth but scarred with bumps, holes, and ridges. These **bone markings,** described and illustrated in **Table 5.1** (p. 142), reveal where muscles, tendons, and ligaments were attached and where blood vessels and nerves passed. There are two categories of bone markings: (a) *projections,* or *processes,* which grow out from the bone surface, and (b) *depressions,* or *cavities,* which are indentations in the bone. You do not have to learn these terms now, but they can help you remember some of the specific markings on bones that we will introduce later in this chapter.

There is a little trick for remembering some of the bone markings listed in the table: All the terms beginning with **T** are projections. The terms beginning with **F** (except *facet*) are depressions.

Microscopic Anatomy

To the naked eye, spongy bone has a spiky, open appearance, whereas compact bone appears to be very dense. Looking at compact bone tissue through a microscope, however, you can see that it has a complex structure (**Figure 5.4**). It is riddled with passageways carrying nerves, blood vessels, and the like, which provide the living bone cells with nutrients and a route for waste disposal. The mature bone cells, **osteocytes** (os′te-o-sītz″), are found within the matrix in tiny cavities called **lacunae** (lah-ku′ne). The lacunae are arranged in concentric circles called **lamellae** (lah-mel′e) around **central (Haversian) canals.** Each complex consisting of central canal and matrix rings is called an **osteon,** or **Haversian system.** Central canals run lengthwise through the bony matrix, carrying blood vessels and nerves to all areas of the bone. Tiny canals, **canaliculi** (kan″ah-lik′u-li), radiate outward from the central canals to all lacunae. The canaliculi form a transportation system that connects all the bone cells to the nutrient supply through the hard bone matrix. Because of this elaborate network of canals, bone cells are well nourished in spite of the hardness of the matrix, and bone injuries heal quickly and well. The communication pathway from the outside of the bone to its interior (and the central canals) is completed by **perforating (Volkmann's) canals,** which run into the compact bone at right angles to the shaft.

Bone is one of the hardest materials in the body, and although relatively light in weight, it has a remarkable ability to resist tension and other forces acting on it. Nature has given us an extremely strong and exceptionally simple (almost crude) supporting system without giving up mobility. The calcium salts deposited in the matrix give bone its hardness, which resists compression. The organic parts (especially the collagen fibers) provide for bone's flexibility and great tensile strength (ability to be stretched without breaking).

DID YOU GET IT?

4. What is the anatomical name for the shaft of a long bone? For its ends?
5. How does the structure of compact bone differ from the structure of spongy bone when viewed with the naked eye?
6. What is the importance of canaliculi?

For answers, see Appendix D.

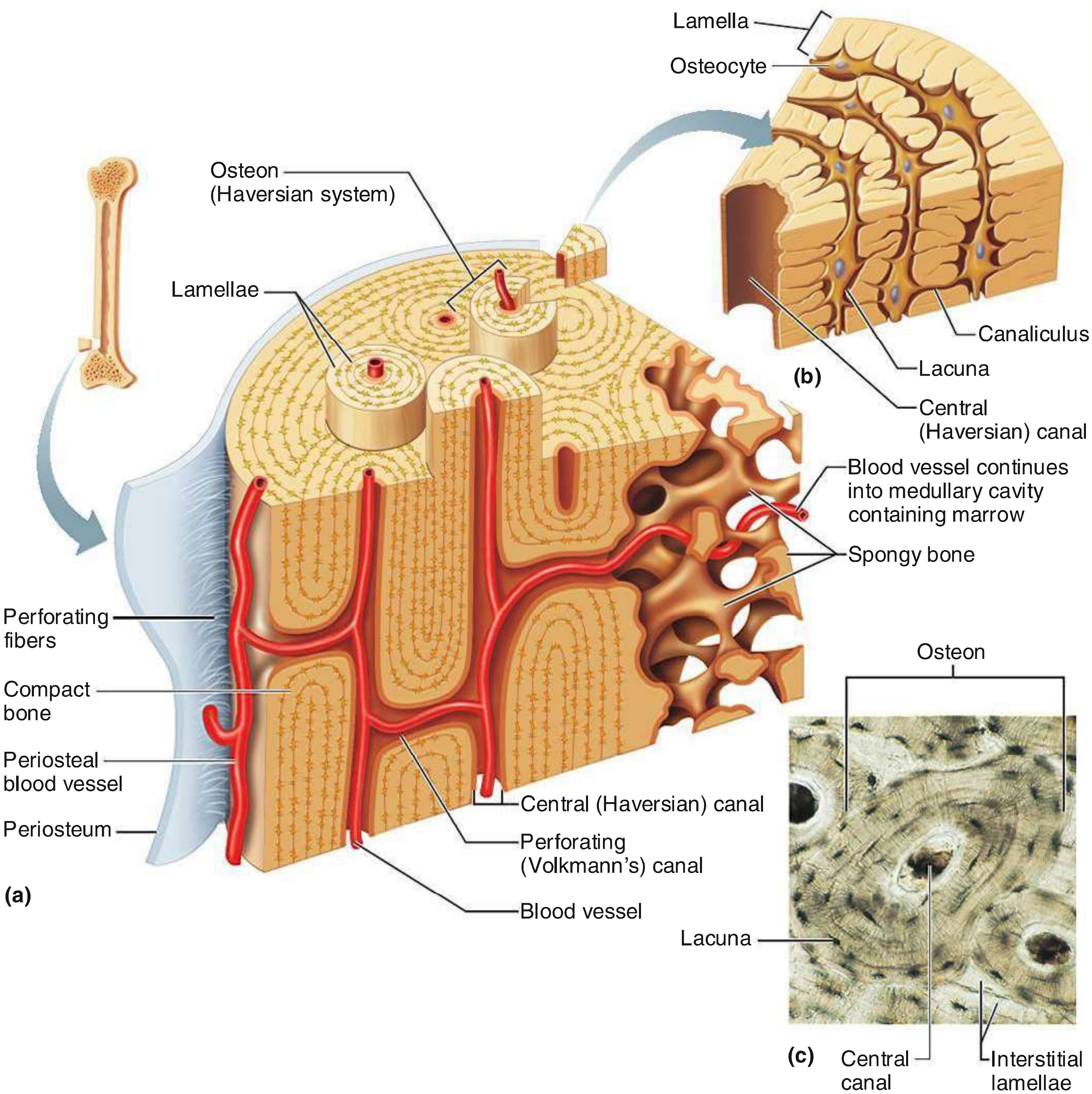


Figure 5.4 Microscopic structure of compact bone. Diagram of a pie-shaped segment of compact bone. (The inset shows a more highly magnified view.) Notice the position of osteocytes in lacunae (cavities in the matrix).

Bone Formation, Growth, and Remodeling

✓ Describe briefly the process of bone formation in the fetus, and summarize the events of bone remodeling throughout life.

The skeleton is formed from two of the strongest and most supportive tissues in the body—cartilage and bone. In embryos, the skeleton is primarily made of hyaline cartilage, but in the young child most of the cartilage has been replaced by bone.

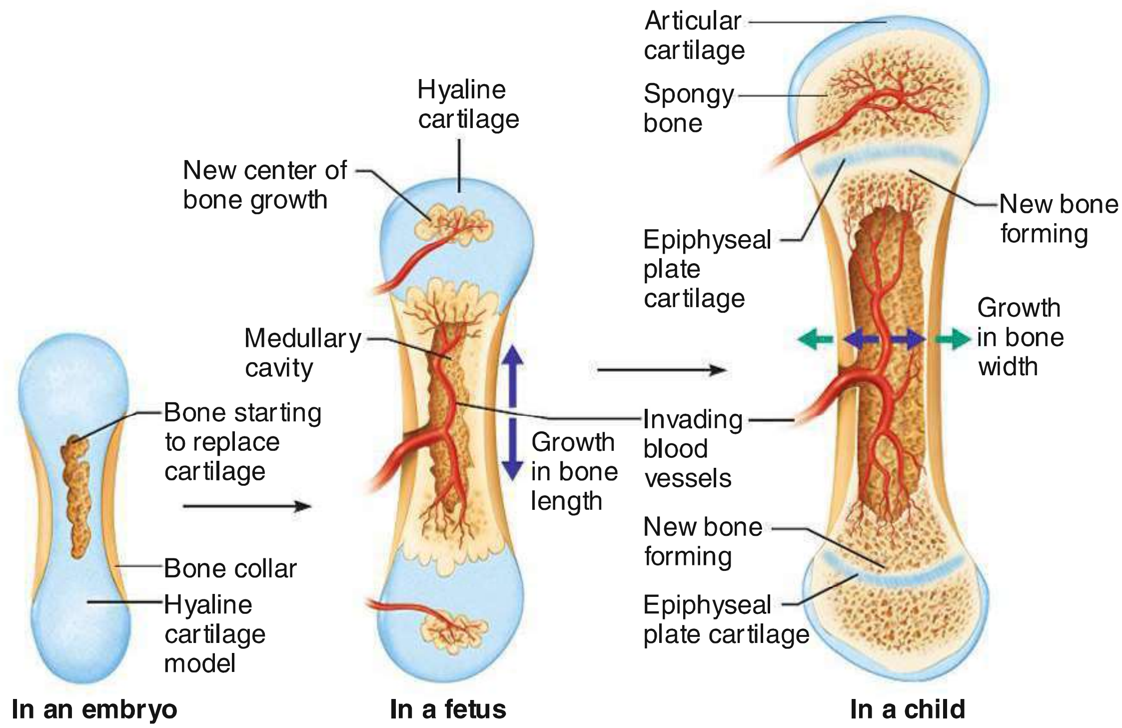


Figure 5.5 Stages of long-bone formation in an embryo, fetus, and young child.

Cartilage remains only in isolated areas such as the bridge of the nose, parts of the ribs, and the joints.

Except for flat bones, which form on fibrous membranes, most bones develop using hyaline cartilage structures as their "models." Most simply, this process of bone formation, or **ossification** (os″ ĭ-f ĭ-ka′shun), involves two major phases (**Figure 5.5**). First, the hyaline cartilage model is completely covered with bone matrix (a bone "collar") by bone-forming cells called **osteoblasts.** So, for a short period, the fetus has cartilage "bones" enclosed by "bony" bones. Then, the enclosed hyaline cartilage model is digested away, opening up a medullary cavity within the newly formed bone.

By birth or shortly after, most hyaline cartilage models have been converted to bone except for two regions—the articular cartilages (that cover the bone ends) and the epiphyseal plates. New cartilage is formed continuously on the external face of the articular cartilage and on the epiphyseal plate surface that faces the bone end (is farther away from the medullary cavity). At the same time, the old cartilage abutting the internal face of the articular cartilage and the medullary cavity is broken down and replaced by bony matrix (**Figure 5.6**).

Growing bones also must widen as they lengthen. How do they widen? Simply, osteoblasts in the periosteum add bone tissue to the external face of the diaphysis as cells called osteoclasts in the endosteum remove bone from the inner face of the diaphysis wall (see Figure 5.6). Because these two processes occur at about the same rate, the circumference of the long bone expands and the bone widens. This process by which bones increase in diameter is called *appositional growth.* This process of long-bone growth is controlled by hormones, the most important of which are *growth hormone* and, during puberty, the *sex hormones.* It ends during adolescence, when the epiphyseal plates are completely converted to bone.

Many people mistakenly think that bones are lifeless structures that never change once long-bone growth has ended. Nothing could be further from the truth; bone is a dynamic and active tissue. Bones are remodeled continually in response to changes in two factors: (1) calcium levels in the blood and (2) the pull of gravity and muscles on the skeleton. We outline how these factors influence bones next.

When blood calcium levels drop below homeostatic levels, the parathyroid glands (located in

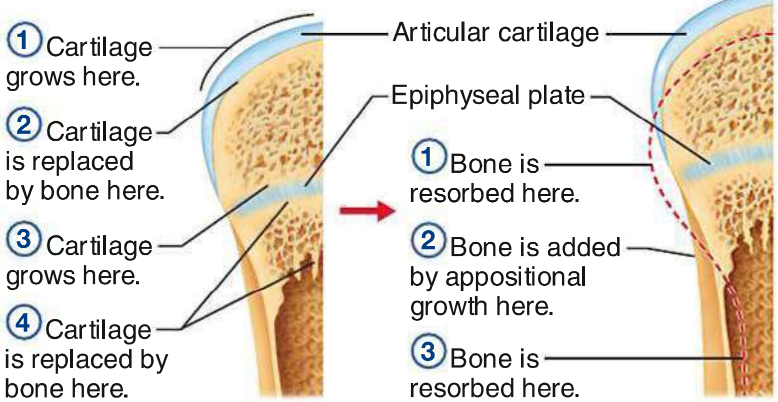


Figure 5.6 Growth and remodeling of long bones. The events at the left depict the process of ossification that occurs at the articular cartilages and epiphyseal plates as the bone grows in length. The events at the right show bone remodeling and appositional growth during long-bone growth to maintain proper bone proportions.

the throat) are stimulated to release parathyroid hormone (PTH) into the blood. PTH activates **osteoclasts,** giant bone-destroying cells in bones, to break down bone matrix and release calcium ions into the blood. When blood calcium levels are too high (*hypercalcemia* [hi″per-kal-se′me-ah]), calcium is deposited in bone matrix as hard calcium salts.

Bone remodeling is essential if bones are to retain normal proportions and strength during long-bone growth as the body increases in size and weight. It also accounts for the fact that bones become thicker and form large projections to increase their strength in areas where bulky muscles are attached. At such sites, osteoblasts lay down new matrix and become trapped within it. (Once they are trapped, they become osteocytes, or mature bone cells.) In contrast, the bones of bedridden or physically inactive people tend to lose mass and to atrophy because they are no longer subjected to stress.

These two controlling mechanisms—calcium uptake and release and bone remodeling—work together. PTH determines *when* (or *if*) bone is to be broken down or formed in response to the need for more or fewer calcium ions in the blood. The stresses of muscle pull and gravity acting on the skeleton determine *where* bone matrix is to be broken down or formed so that the skeleton can remain as strong and vital as possible.

HOMEOSTATIC IMBALANCE

Rickets is a disease of children in which the bones fail to calcify. As a result, the bones soften, and the weight-bearing bones of the legs show a definite bowing. Rickets is usually due to a lack of calcium in the diet or lack of vitamin D, which is needed to absorb calcium into the bloodstream. Rickets is not seen very often in the United States. Milk, bread, and other foods are fortified with vitamin D, and most children drink enough calcium-rich milk. However, it can happen in infants nursed by mothers who become vitamin D-deficient over the course of a long gray winter, and it remains a problem in some other parts of the world.

DID YOU GET IT?

7. Bones don't begin as bones. What do they begin as?

8. Which stimulus—PTH (a hormone) or mechanical forces acting on the skeleton—is more important in maintaining blood calcium levels than in maintaining bone strength?

9. If osteoclasts in a long bone are more active than osteoblasts, what change in bone mass is likely to occur?

For answers, see Appendix D.

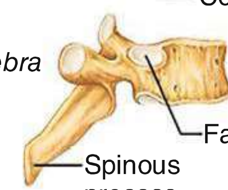
(Continues on page 144)

Table 5.1 Bone Markings

Projections that are sites of muscle and ligament attachment

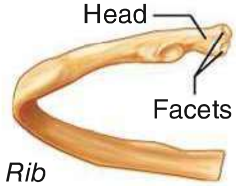
Name of bone marking	Description
Tuberosity	Large, rounded projection; may be roughened
Crest	Narrow ridge of bone; usually prominent
Trochanter (tro-kan′ter)	Very large, blunt, irregularly shaped process (the only examples are on the femur)
Line	Narrow ridge of bone; less prominent than a crest
Tubercle (too′ber-kl)	Small, rounded projection or process
Epicondyle	Raised area on or above a condyle
Spine	Sharp, slender, often pointed projection
Process	Any bony prominence

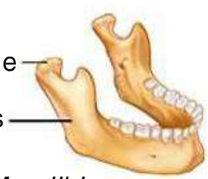
Illustration



Projections that help to form joints

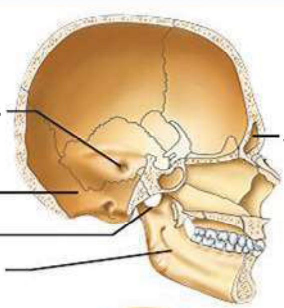
Head	Bony expansion carried on a narrow neck
Facet	Smooth, nearly flat articular surface
Condyle (kon′dīl)	Rounded articular projection
Ramus (ra′mus)	Armlike bar of bone

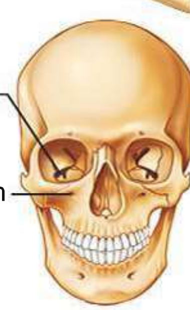




Depressions and openings

For passage of blood vessels and nerves	
Groove	Furrow
Fissure	Narrow, slitlike opening
Foramen (fo-ra′men)	Round or oval opening through a bone
Notch	Indentation at the edge of a structure
Others	
Meatus (me-a′tus)	Canal-like passageway
Sinus	Cavity within a bone, filled with air and lined with mucous membrane
Fossa (fos′ah)	Shallow, basinlike depression in a bone, often serving as an articular surface





Radiologic Technologist

Radiologic technologists supply critical information that allows doctors to make accurate diagnoses.

"You never know what's going to walk in the door, really," says Maggie Regalado, a radiologic technologist at Dell Children's Hospital in Austin, Texas. "In an emergency room, you see kids who swallowed something, car accident victims, all kinds of things." Regalado and her coworkers operate X-ray equipment and must be ready to do everything from preparing patients for MRIs to chest X rays in the operating room for an accident victim.

Regalado became interested in radiology after her father strongly suggested it to her. Fortunately for Regalado, anatomy was her favorite class, because it's an important one for radiologic technologists. After getting her associate's degree in diagnostic imaging, she completed both state and national certification. To keep her certification current, she must do 24 hours of continuing education every two years.

You don't want to make errors, because one thing you do wrong could cost this patient his or her life.

"I didn't realize how big a field it was," she says. With X rays you're constantly moving from here to there, from surgery to the neonatal intensive care unit and so on." As you might guess, radiologic technologists, especially in hospitals, must be prepared to spend a lot of time on their feet and to think quickly. Regalado described one case when a two-car accident sent five children to the trauma unit. The radiologic technologists had to work quickly to help the doctors see what injuries the children suffered—and almost as importantly, to make sure not to mix up anyone's X rays.

"You don't want to make errors, because one thing you do wrong could cost this patient his or her life." she says. "Even though radiology can get emotional, you have to drop all that and stay technical with your job."

"We can't see your bones with our bare eyes, so we have to make sure we position you correctly. Then also, if you say, 'It hurts here,' I'll call the doctor and see if he wants to do a different type of X ray."

Regalado enjoys working with the patients at Dell. Getting children to remain perfectly still and positioned correctly is a challenge, but the imaging department has toys and televisions to distract them. For babies who cannot easily hold still or understand why they need to, there are various devices to position them appropriately.

"We have a lot of interaction with the patients, with the patient's family, we try to joke around and make them happy," she say. "When we make the child happy, then the parents are happy."

In a hospital setting, radiologic technologists are needed 24 hours a day, and often are required to be on-call in addition to their regular shifts. Technologists who work in clinics usually have a more traditional 9-to-5 schedule. Depending on the clinic, these technologists may also specialize in areas such as ultrasound, mammography, magnetic resonance imaging (MRI), or computed tomography (CT).

For more information contact:

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