Bone

Introduction and Key Concepts for Bone

Bone is a special type of supporting connective tissue, which has a hard, mineralized, extracellular matrix containing **osteocytes** embedded in the matrix. It is different from cartilage in that bone is calcified and, hence, is harder and stronger than cartilage. In addition, it has many blood vessels penetrating the tissue. Bone protects internal organs, provides support for soft tissues, serves as a calcium reserve for the body, provides an environment for blood cell production, detoxifies certain chemicals in the body, and aids in the movement of the body. In general, the external surface of the bone is covered by **periosteum**, a layer of connective tissue containing small blood vessels, osteogenic cells, and nerve fibers conveying pain information. The inner surface of the bone is covered by **endosteum**, a thin connective tissue layer composed of a single layer of osteoprogenitor cells and osteoblasts that lines all internal cavities within bone; this lining represents the boundary between the bone matrix and the marrow cavities. Bone cells include **osteogenic cells, osteoblasts, osteocytes,** and **osteoclasts**. These cells contribute to bone growth, remodeling, and repair.

Bone Matrix

Bone is primarily characterized by a hard matrix, which contains calcium, phosphate, other organic and inorganic materials, and type I collagen fibers. Compared to cartilage, bone contains only about 25% water in the matrix, whereas cartilage matrix contains about 75% water. This combination makes bone hard, firm, and very strong. **Bone matrix** has **organic** and **inorganic components**. (1) *Organic (noncalcified) matrix* is mainly **type I collagen** with nonmineralized ground substance (chondroitin sulfate and keratin sulfate). It is found in the freshly produced bone matrix, **osteoid** (also called **prebone**), which is produced by **osteoblasts**. This matrix stains light pink in H&E preparations (Fig. 5-11A). (2) *Inorganic (calcified) matrix*, mainly in the form of **hydroxyapatite**, contains crystalline mineral salts, mostly of calcium and phosphorus. After osteoid is produced, this fresh matrix undergoes a mineralization process to become the calcified matrix (Fig. 5-11B).

Bone Cells

The main types of cells in bone are **osteoprogenitor cells**, **osteoblasts**, **osteocytes**, and **osteoclasts**: (1) *Osteoprogenitor cells* are located in the **periosteum** on the surface of the growing bone and can differentiate into osteoblasts. (2) *Osteoblasts* produce the bone matrix. They are cuboidal or low columnar in shape and have a well-developed **Golgi complex** and **RER**, which correlates with their protein-secreting function (Fig. 5-11). The overall process of mineralization relies on the elevation of calcium and phosphate within the matrix and the function of **hydroxyapatite crystals**. This is brought about by complex functions of the osteoblast. (3) *Osteocytes* are small, have cytoplasmic processes, and are unable to divide. These cells originate from osteoblasts and are embedded in the bone matrix. Osteoblasts deposit the matrix around themselves and end up inside the matrix, where they are called "osteocytes." Each osteocyte has many long, thin processes that extend into small narrow spaces called **canaliculi**. The nucleus and surrounding cytoplasm of each osteocyte occupy a space in the bone matrix called a **lacuna**. Thin processes of the osteocyte course through thin channels (canaliculi) that radiate from each lacuna and connect neighboring lacunae (Fig. 5-9B,C). (4) *Osteoclasts* are large, multinucleated cells, which derive from **monocytes**, absorb the bone matrix, and play an essential role in bone remodeling (Fig. 5-14A,B).

Types of Bone

There are several ways to classify bone tissues. Microscopically, bone can be classified as **primary bone** (**immature**, or "**woven**" **bone**) and **secondary bone** (**mature**, or **lamellar bone**). Bones can also be classified by their shapes as follows: **long bones**, **short bones**, **flat bones**, and **irregular bones** (Table 5-2). *Mature bone* can be classified as **compact bone** and **cancellous bone** based on gross appearance and density of the bone. *Compact bone*, also called **cortical bone**, has a much higher density and a well-organized osteon system. It does not have trabeculae and usually forms the external aspect (outside portion) of the bone (Figs. 5-8 to 5-10B). *Cancellous bone*, also called **spongy bone**, has a much lower density and contains **bony trabeculae or spicules** with intervening bone marrow (Fig. 5-8A,C). It can be found between the inner and the outer tables of the skull, at the ends of long bones, and in the inner core of other bones.

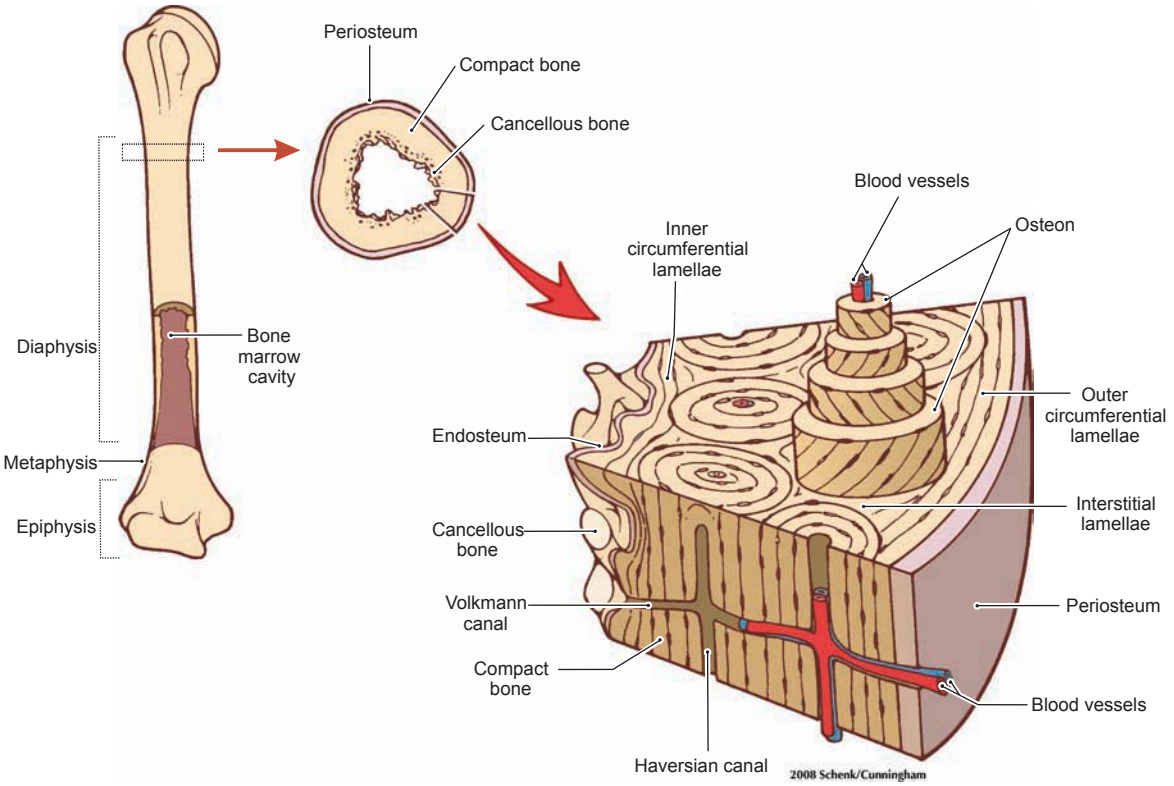

Figure 5-8. **Overview of bone structure, long bone.**

Bones can be classified as **long bones**, **short bones**, **flat bones**, and **irregular bones** according to their shape. *Long bones* are longer than they are wide and consist of a long shaft (**diaphysis**) and two ends (**epiphyses**). *Short bones* are roughly cube shaped, such as wrist and ankle bones. Bone also can be classified as **compact bone** and **cancellous bone** based on gross appearance and bone density. The **diaphysis** of a long bone is composed primarily of *compact bone* and an inner medullary cavity, which is filled with **bone marrow**. The **epiphyses** of long bones are composed mainly of *cancellous* (*spongy*) *bone*, and the articular surfaces are covered by articular cartilage, providing a smooth joint surface for articulation with the next bone. The **metaphysis** is a transitional zone between the diaphysis and epiphysis; it represents the level that cancellous bone ends and the bone marrow cavity begins. The external surfaces of compact bone are covered by **periosteum**, a thick layer of dense connective tissue, which contains **blood vessels**. **Endosteum**, a thin layer of connective tissue with a single layer of osteoprogenitor cells and osteoblasts, forms a boundary between the bone and the medullary cavity (this layer may be continuous with the trabeculae of the cancellous bone). The general structure of compact bone includes (1) the **osteon**, a canal surrounded by layers of concentric lamellae; (2) **interstitial lamellae**, lamellae layers in between the osteons; (3) **outer circumferential lamellae**, outer layers of lamellae located beneath the periosteum and surrounding the outside of the entire compact bone; and (4) **inner circumferential lamellae**, layers of lamellae located beneath the endosteum and forming the innermost layer of compact bone. The **Haversian canal** is a central space through which blood vessels pass; the **Volkmann canal** is the space that sits perpendicularly to the Haversian canals and forms the connection between two Haversian canals.

Types of Bone

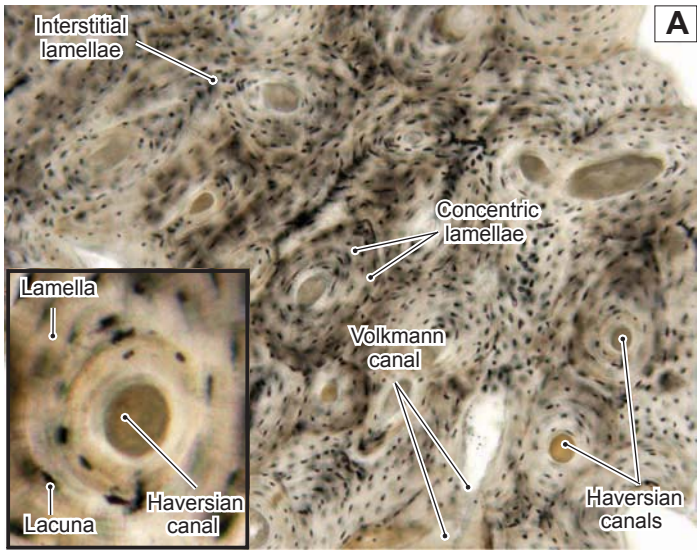

Figure 5-9A. Compact bone. Ground specimen (unstained), ×68; inset ×212

A cross section of **compact bone** in a ground specimen (without decalcification of tissue) is shown. **Haversian canals** are round central spaces in the cross-sectional view; a **Volkmann canal** is shown in the longitudinal view. Volkmann canals run perpendicularly to and connect Haversian canals with each other (Fig. 5-8). The *inset photomicrograph* shows an **osteon** (**Haversian system**), the basic structural unit of compact bone, which includes a **Haversian canal**, **lacunae** with housed **osteocytes**, and **concentric lamellae** (Fig. 5-9C). Bone matrices located between the osteons are called **interstitial lamellae**.

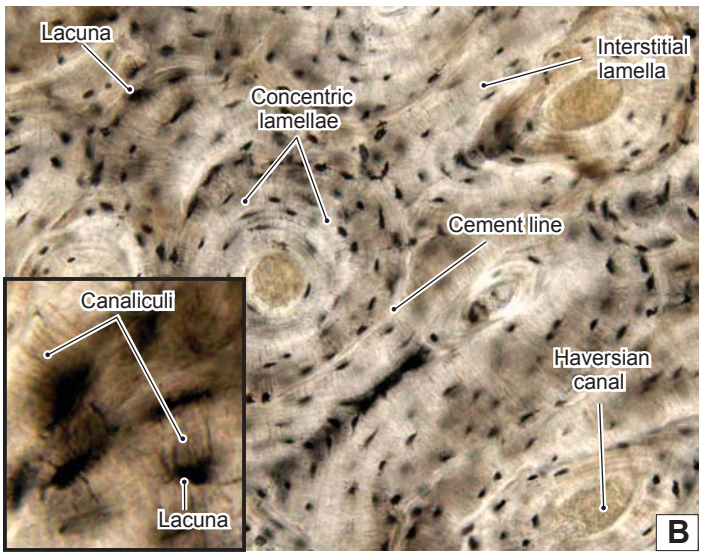

Figure 5-9B. Compact bone. Ground specimen (unstained), ×136; inset ×388

A higher power view of compact bone in ground specimen is shown. **Concentric lamellae** and **lacunae** are arranged in rings, which surround the **Haversian canal**. Each lacuna has an osteocyte in it. Tiny canals called **canaliculi** contain processes of osteocytes and link the lacunae with each other. The canaliculi permit the osteocytes to communicate via gap junctions where the processes of adjacent osteocytes touch each other inside the canaliculi. A **cement line** forms a boundary between adjacent osteons. Compact bone forms the hard external portion of bone and provides strong support and protection.

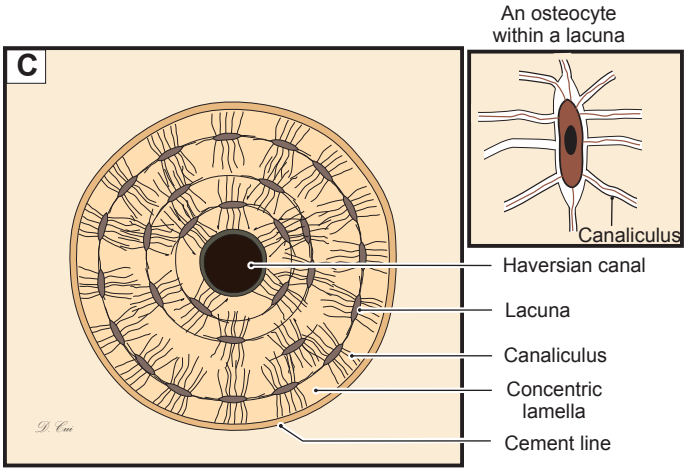

Figure 5-9C. A representation of an osteon of the compact bone.

The **osteon**, also called a **Haversian system**, is the basic unit of the compact bone structure. It has concentrically arranged laminae (concentric lamellae) surrounding a centrally located Haversian canal. The Haversian system consists of (1) a **Haversian canal** through which blood vessels pass, (2) **concentric lamellae**, (3) **lacunae**, each one of which contains an osteocyte, (4) **canaliculi**, which are small narrow spaces containing osteocyte processes, and (5) a **cement line**, the thin dense, external bony layer that surrounds each osteon.

A schematic drawing illustrates an **osteocyte** occupying a **lacuna** (a space in the bone matrix that houses an osteocyte) and its thin processes within the canaliculi. The hairlike processes of the osteocyte are in contact with the processes of adjacent osteocytes and provide a means of communication between osteocytes.

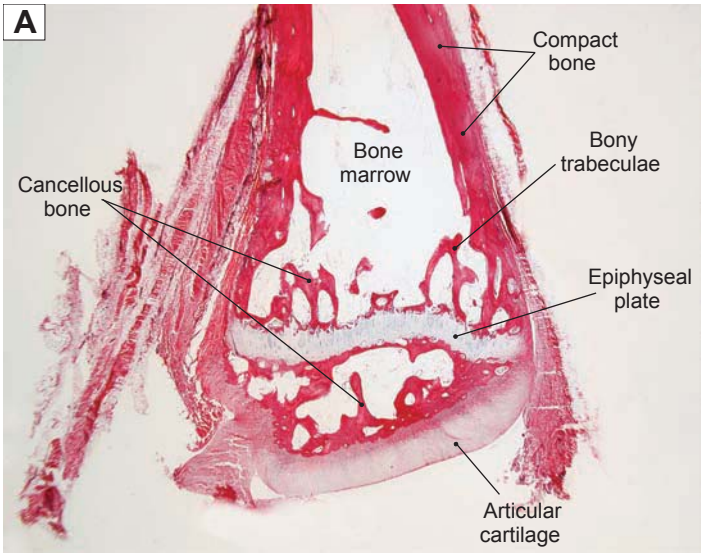

Figure 5-10A. Compact bone and cancellous bone, finger. Decalcified bone, H&E, ×11

Bone has a calcified extracellular matrix that is very difficult to cut into thin sections. In order to have thin sections with H&E stain, these bone specimens have to go through a decalcification process that removes calcium compounds from the specimen. Bone can be classified as **compact bone** (**cortical bone**) and **cancellous bone** (**spongy bone**), based on its gross appearance. *Compact bone* has a very high density and a well-organized osteon system (Figs. 5-8 and 5-9A–C). It has no trabeculae and usually forms the external aspect of a bone. *Cancellous bone* (*spongy bone*) has a much lower density and contains **bony trabeculae** or **spicules** with intervening **bone marrow**. It usually forms the inner part of a bone, also called **medullary bone**, and is commonly found between the inner and the outer tables of the skull, at the ends of long bones (limbs and fingers), and in the cores of other bones.

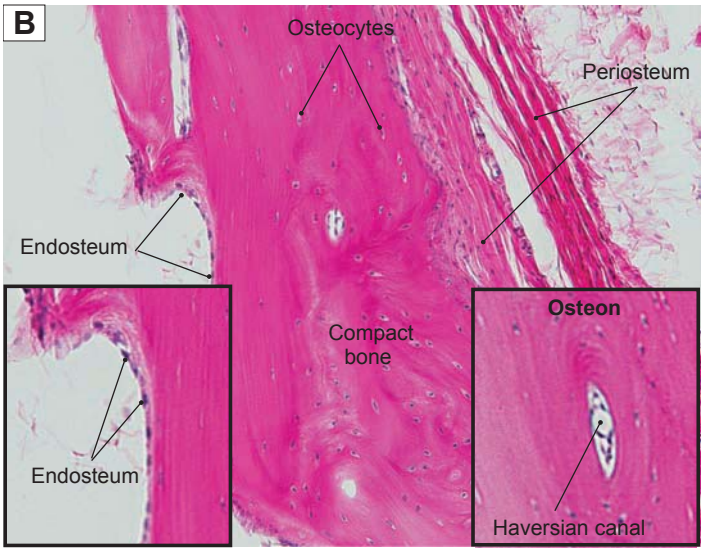

Figure 5-10B. Compact bone, finger. Decalcified bone, H&E, ×105; inset (*left*) ×154; inset (*right*) ×127

An example of **compact bone** from the diaphysis of the long bone (finger) is shown. The internal surface is covered by a single layer of connective tissue cells forming the **endosteum**. It contains osteoprogenitor cells, which are capable of differentiating into osteoblasts. The external surface is covered by a thicker layer, the **periosteum**, which contains blood vessels, nerves, and osteoprogenitor cells. Osteoprogenitor cells can differentiate into **osteoblasts**, which have the ability to produce bone matrix, **osteoid** (**prebone**) (Fig. 5-11A). Blood vessels branch to supply bone through a system of interconnected **Volkmann canals** and **Haversian canals** (Fig. 5-8). **Osteocytes** are arranged uniformly in compact bone. Each osteocyte occupies one lacuna, which has no isogenous group as it does in cartilage (Fig. 5-9C).

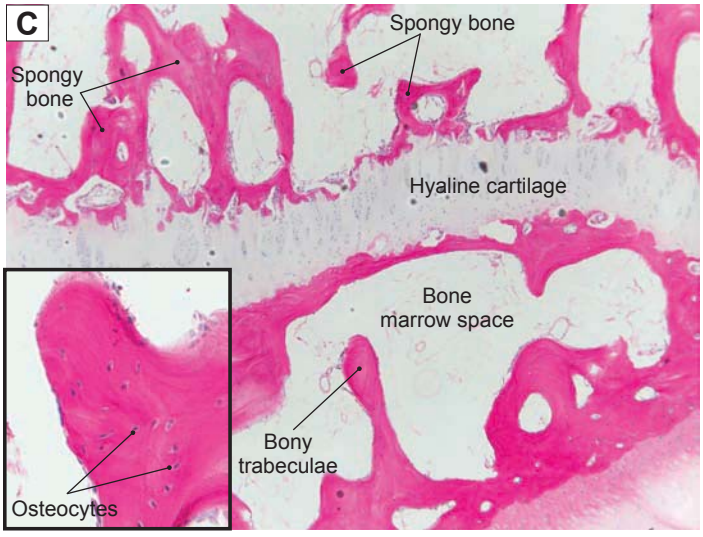

Figure 5-10C. Cancellous bone (spongy bone), nasal. Decalcified bone, H&E, ×34; inset ×128

Cancellous bone is also called **spongy bone**. It has a lower density than compact bone and consists of **bony trabeculae**, or **spicules**, within a marrow-filled cavity. Osteoblasts line the surface of the bony trabeculae. Cancellous bone displays irregular shapes in the trabecular network. **Bone marrow** fills the space between the bony trabeculae (Fig. 5-11A). Most osteocytes in the matrix are arranged in an irregular pattern rather than in circular rings (Fig. 5-8). Cancellous bone mainly forms the inner core of bone and provides (1) a meshwork frame that supports and reduces the overall weight of bone and (2) room for blood vessels to pass through and a place for marrow to function as a hemopoietic compartment, housing and producing blood cells (Fig. 5-11A).

Types of Bone	Gross Appearance (Shape)	Characteristics	Main Locations	Main Functions
Classification Based on Gross Appearance				
Compact bone	Uniform; no trabeculae and spicules	Higher density; lamellae arranged in circular pattern	Outer portion of the bone (cortical bone)	Protection and support
Cancellous (spongy) bone	Irregular shape; trabeculae and spicules present; surrounded by the bone marrow cavities	Lower density; lamellae arranged in parallel pattern	Inner core of the bone (medullary bone)	Support; blood cell production
Classification Based on Shape				
Long bone	Longer than it is wide	Consists of diaphysis (long shaft) and two epiphyses at the ends	Limbs and fingers	Support and movement
Short bone	Short, cube shaped	A thin layer of compact bone outside and thick cancellous bone inside	Wrist and ankle bones	Movement
Flat bone	Flat, thin	Two parallel layers of compact bone separated by a layer of cancellous bone	Many bones of the skull, ribs, scapulae	Support; protection of brain and other soft tissues; blood cell production
Irregular bone	Irregular shape	Consists of thin layer of compact bone outside and cancellous bone inside	Vertebrae and bones of the pelvis	Support; protection of the spinal cord and pelvic viscera; blood cell production
Classification Based on Microscopic Observation				
Primary bone (immature bone)	Irregular arrangement	Lamellae without organized pattern; not heavily mineralized	Developing fetus	Bone development
Secondary bone (mature bone)	Regular arrangement	Well-organized lamellar pattern; heavily mineralized	Adults	Protection and support