LONG BONE STRUCTURE

CN: Use light blue for C, a tan color for D, very light colors for E and F, yellow for I, and red for J. (1) The title "red marrow" is not to be colored as the red marrow in this bone is not shown, having been replaced by yellow marrow during maturity. Only part of the yellow marrow in the medullary cavity is shown. Leave the cavity (G) itself uncolored. (2) Color the vertical bar to the right which represents the epiphysis (A) and the diaphysis (B) of the long bone.

Bone is a living, vascular structure, composed of organic tissue (cells, fibers, extracellular matrix, vessels, nerves—about 35% of a bone's weight) and mineral (calcium hydroxyapatite—about 65% of a bone's weight). Bone functions as a support structure, a site of attachment for skeletal muscle, ligaments, tendons, and joint capsules, a source of calcium, and a significant site of blood cell development (hematopoiesis) for the entire body. Here we show a long bone, specifically the femur, the bone of the thigh.

EPIPHYSIS A

The epiphysis is the end of a long bone or any part of a bone separated from the main body of an immature bone by cartilage. It is formed from a secondary site of ossification. It is largely cancellous bone, and its articulating surface is lined with 3–5 mm of hyaline (articular) cartilage. The epiphysis is supplied by vessels from the joint capsule.

DIAPHYSIS B

The diaphysis is the shaft or central part of a long bone. It has a marrow-filled cavity (medullary cavity) surrounded by compact bone which is lined externally by periosteum and internally by endosteum (not shown). The diaphysis is formed from one or more primary sites of ossification and is supplied by one or more nutrient arteries.

ARTICULAR CARTILAGE C

Articular cartilage is smooth, slippery, porous, malleable, insensitive, and bloodless; it is the only remaining evidence of an adult bone's cartilaginous past. It is massaged by movement, permitting absorption of synovial fluid, oxygen, and nutrients. Articular (hyaline) cartilage is also nourished by vessels from the subchondral bone. Bones of a synovial joint make physical contact at their cartilaginous ends. The degenerative process of arthritis involves the breakdown and fibrillation of articular cartilage.

PERIOSTEUM D

Periosteum is a fibrous, cellular, vascular, and highly sensitive life support sheath for bone, providing nutrient blood for bone cells and a source of osteoprogenitor cells throughout life. It does not cover articular cartilage.

CANCELLOUS (SPONGY) BONE E

Cancellous (spongy) bone consists of interwoven beams (trabeculae) of bone in the epiphyses of long bones, the bodies of the vertebrae, and other bones without cavities. The spaces among the trabeculae are filled with red or yellow marrow and blood vessels. Cancellous bone forms a dynamic latticed truss capable of mechanical alteration (reorientation, construction, destruction) in response to the stresses of weight, postural change, and muscle tension.

COMPACT BONE F

Compact bone is dense bone characterized in long bones by microscopic hollow cylinders of bone (haversian systems) interwoven with non-cylindrical lamellae of bone. It forms the stout walls of the diaphysis of long bones and the thinner outer surface of other bones where there is no articular cartilage—e.g., the flat bones of the skull. Blood vessels reach the bone cells by a system of integrated canals.

MEDULLARY CAVITY G

The medullary cavity is the cavity of the diaphysis. It contains marrow: red in the young, turning to yellow in many long bones in maturity. It is lined by endosteal tissue (thin connective tissue with many osteoprogenitor cells).

RED MARROW

Red marrow is a red, gelatinous substance composed of red and white blood cells in a variety of developmental forms (hematopoietic tissue) and specialized capillaries (sinusoids) enmeshed in reticular tissue. In adults, red marrow is generally limited to the sternum, vertebrae, ribs, hip bones, clavicles, and cranial bones.

YELLOW MARROW H

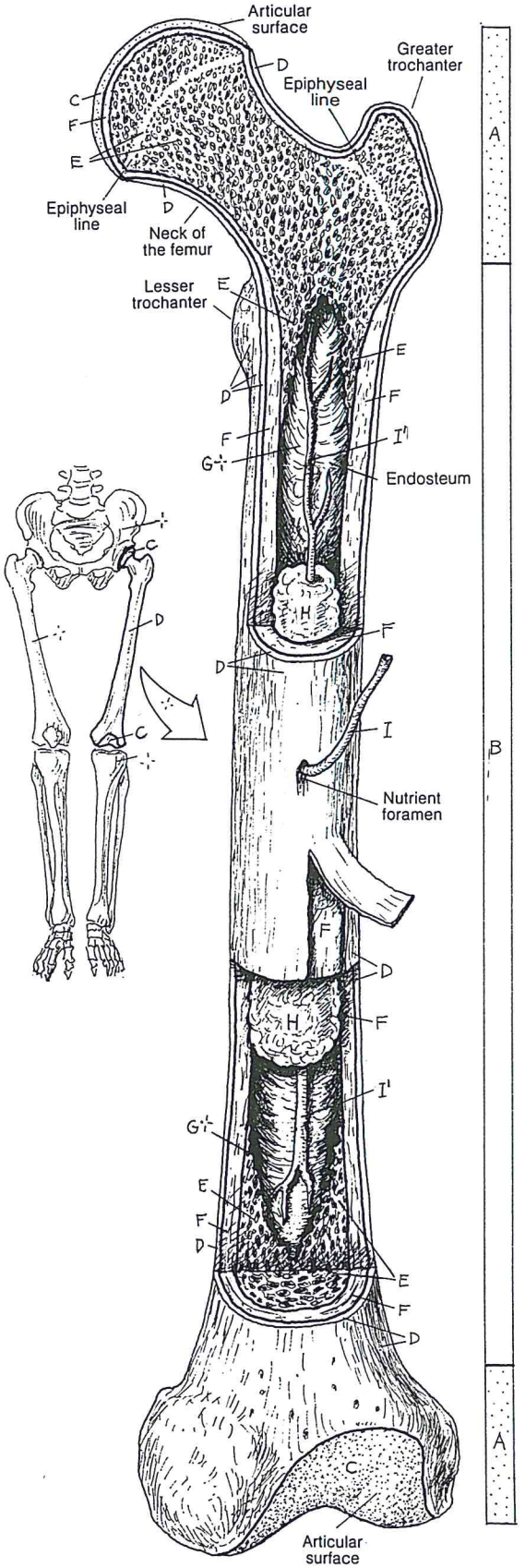
Yellow marrow is fatty connective tissue that is not productive of blood cells. It replaces red marrow in the epiphyses and medullary cavities of long bones, and cancellous bone of other bones.

NUTRIENT ARTERY I /BRANCHES I'

The nutrient artery is the principal artery and major supplier of oxygen and nutrients to the shaft or body of a bone; its branches snake through the labyrinthine canals of the haversian systems and other tubular cavities of bones.

ANTERIOR VIEW
(Left femur)

Coronal section through proximal epiphysis and dissection of medullary cavity



STRUCTURE AND GROWTH OF BONE

Bones are the building blocks of the skeleton, which supports the body and provides leverage for muscles and movement. In addition, bones harbor the brain, spinal cord, and bone marrow and provide a storehouse for calcium. In response to hormonal stimulation, bone calcium can be readily exchanged with plasma calcium, preventing alterations in the level of this important ion in the blood. (See plate 114).

Although bone appears hard and inert, it is in fact an active tissue, supplied by nerves and blood vessels. Various bone cells (see below) are continuously active, even in the adult, building and rebuilding, repairing and remodeling the bone in response to strains, stresses, and fractures.

BONE STRUCTURE. To understand bone structure, let us examine a typical long bone such as the tibia. It consists of two heads (*epiphysis*) and a shaft (*diaphysis*). A cross-section of the long bone reveals dense and cavernous areas. Dense areas contain *compact bone*; cavernous areas consist of *spongy bone*. Diaphysis of a long bone contains mainly compact bone; epiphysis contains both compact and long bone.

Microscopic examination of the compact bone in the diaphysis reveals many cylindrical units, called the *Haversian systems* (osteon). These units, which run along the bone length, are packed tightly and held together by a special cement. Each Haversian system consists of concentric plates (lamella) surrounding a central canal through which *blood vessels* and *nerves* run. The central canal communicates with numerous smaller *lacunae* located throughout the Haversian system. The many lacunae in turn communicate via smaller passageways (canaliculi), which permit blood and nerves to reach bone cells.

Physiologically, bone tissue consists of two compartments: first, a metabolically active cellular compartment made up of *bone cells* and second, a metabolically inert extracellular compartment, the *bone matrix*, consisting of a mixture of organic and inorganic materials. The organic part is made of *collagen* fibers, extremely tough fibrous proteins, and the *ground substance* (*glycoproteins* and *mucopolysaccharides*). The inorganic part of the bone matrix consists of a mineral of calcium and phosphate ($Ca_{10}[PO_4]_6[OH]_2$) — *hydroxyapatite crystals*. To make the bone matrix, the hydroxyapatite crystals are deposited on a mesh of collagen fibers and glycoproteins, a process called *calcification*. The calcified matrix gives the bone its remarkable hardness and strength.

BONE CELLS. Bone cells are *osteoblasts*, *osteocytes*, and *osteoclasts*. Osteoblasts, usually found near the bone surfaces, are the young bone cells that secrete the organic substances of the matrix. Once totally surrounded by the secreted matrix, osteoblasts markedly diminish their bone-making activity. At this stage, they are considered mature and referred to as osteocytes. Osteocytes are found in or near the lacunae. They develop extensive processes (filopodia) that run through the canaliculi, connecting with the other osteocytes. These membranous process facilitate the exchange of nutrients, especially calcium between the bone and blood.

The third type of bone cell is the osteoclast, which resembles the blood macrophages. Osteoclasts have important functions in repairing fractures and remodeling new bone. To accomplish their tasks, osteoclasts secrete *lysosomal enzymes* (e.g., the protease collagenase) into the bone matrix. These enzymes digest the matrix proteins, liberating calcium and phosphate. Thus, osteoclasts, in addition to their involvement in remodeling and repairing of fractures, are targets for hormones, such as parathormone, that promote bone resorption and calcium mobilization.

BONE GROWTH. The development of bone is usually preceded by the formation of cartilage, a type of connective tissue. In long bone, the growth and elongation begins during the postnatal period, continuing through adolescence. Elongation is achieved by the activity of two cartilaginous plates, called the *epiphyseal plates*, located between the shaft and the heads. Germinal cells in these plates continuously produce new cartilage cells, which migrate toward the shaft, where they form a template. Next, bone cells move into these areas, constructing new bone over these templates. In this manner, the length of the shaft increases at both ends, and the head move progressively apart. As growth proceeds, the thickness of epiphyseal plates gradually decreases. The plates are thus wide in growing children, narrow after puberty and disappearing entirely by adulthood (*epiphyseal closure*). Longitudinal growth is not possible after this stage, which occurs at different ages for different bones.

HORMONAL REGULATION OF BONE GROWTH. During childhood, *thyroid* and *growth hormones* stimulate plate growth. *Androgens* stimulate bone growth in puberty and are important in the *adolescent growth spurt*. However, in late adolescence, androgens enhance the closure of epiphyseal plates, thus terminating growth. In adults, excess GH promotes bone growth only in width, leading to the thick bones characteristic of *acromegalic* individuals (see plate 112).

FRACTURE REPAIR. During repair of a fracture, a special type of connective tissue, the *hyaline cartilage*, develops at the fracture site, forming a *callus*. The callus serves as a model for new bone growth and protects the healing bone against the deforming stress forces acting on it. When new bone replaces the callus, osteoclasts remodel the bone into its original shape by digesting the extra bone.

CN: Use red for A, a pale yellow or tan for B, and very light colors for C and D.

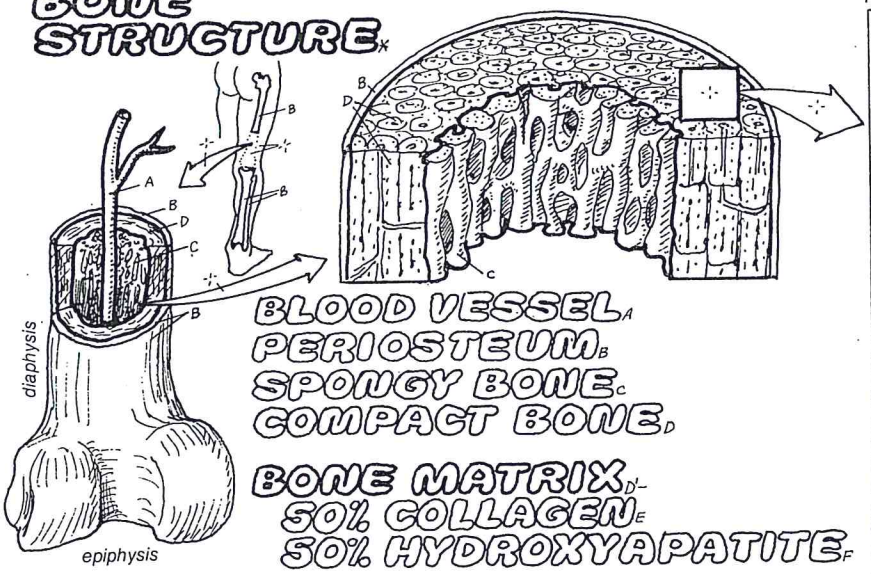
1. Begin with the bone structures at the top. Notice that only one group of Haversian systems (D¹) has been selected for coloring.

2. Color the three types of bone cells and two illustrations underneath demonstrating their functions.

3. Color the three steps in fracture repair.

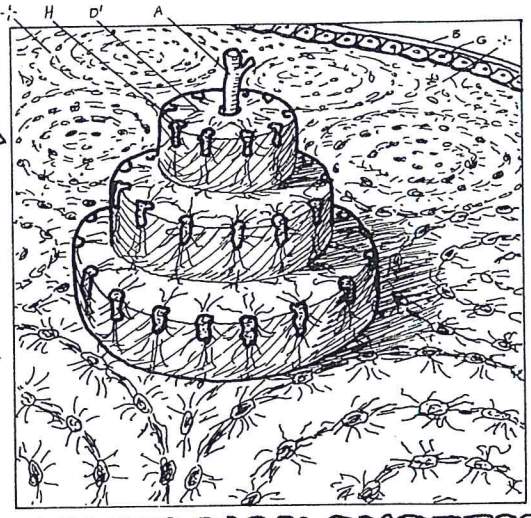
4. Color the hormonal regulation of bone growth shown at the bottom.

BONE STRUCTURE



BLOOD VESSEL A
PERIOSTEUM B
SPONGY BONE C
COMPACT BONE D

BONE MATRIX D'
50% COLLAGEN E
50% HYDROXYAPATITE F

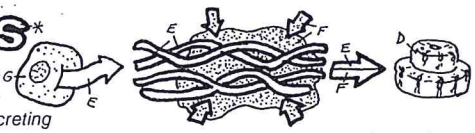


HAVERSIAN SYSTEMS D'

Spongy bone contains cavities, compact bone does not. Mature bone is lamellar. Several concentric lamella form a cylindrical unit, the Haversian system (osteon). A Haversian canal at its middle contains blood vessels and nerves. A long bone consists of numerous Haversian systems running parallel to bone length.

BONE CELLS *

OSTEOBLAST G



Osteoblasts are bone-forming cells, secreting collagen into the bone matrix.

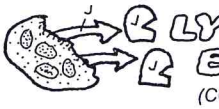
Bone matrix is a mixture of organic and mineral elements. Collagen fibers and glycoproteins form an organic net overlaid by calcium phosphate crystals, producing the hard material of bone.

OSTEOCYTE H

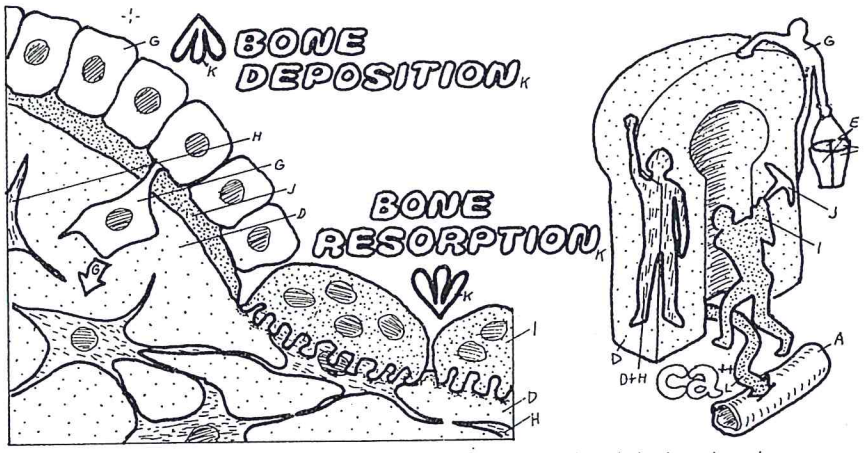
Osteocytes are mature osteoblasts. Their processes engage in metabolic exchange with blood.

OSTEOCLAST I

Osteoclasts are polynucleated macrophage-like cells that digest bone matrix by secreting protease enzymes.



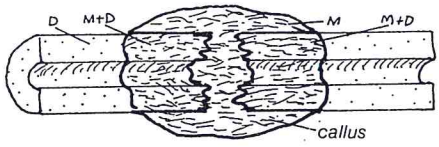
LYSOSOMAL ENZYMES J
(COLLAGENASE)



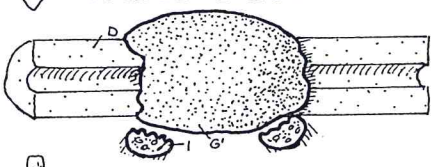
During bone formation, osteoblasts act as builders, secreting matrix proteins. Calcification of matrix isolates osteoblasts, maturing in osteocytes with extensive processes. Osteocyts participate in exchange of nutrients and calcium with blood. Osteoclasts help shape bone by digesting extra pieces. When stimulated by PTH, calcium released by osteoclastic digestion is transported to blood to compensate for calcium deficiency.

FRACTURE REPAIR *

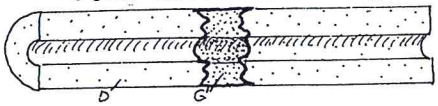
HYALINE CARTILAGE M



NEW BONE G'



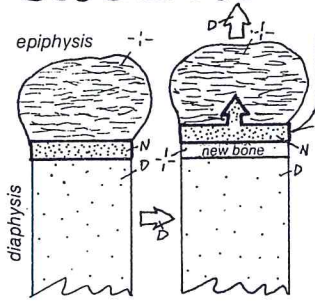
REMODELED G'



At edges of bone fractures, hyaline cartilage proliferates forming a callus. This helps support fracture and serves as a model for bone formation. Infiltration by bone cells transforms callus to bone which is then remodelled and shaped by digestive actions of osteoclasts.

GROWTH *

EARLY YOUTH *

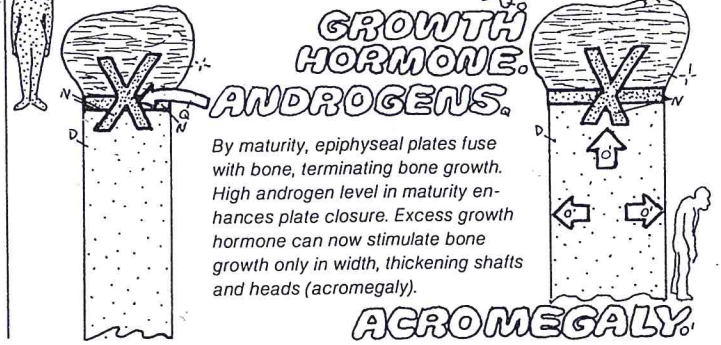


GROWTH HOR. O
THYROID HOR. P
ANDROGENS Q

In long bone growth, epiphyseal plates (hyaline cartilage) expand, forming new cells. These form bone models at shaft ends. Bone is formed on this model, increasing shaft length. Growth hormone, thyroxine and androgens stimulate plate growth.

EPIPHYSEAL PLATE N

MATURITY * "epiphyseal closure"



GROWTH HORMONE O
ANDROGENS Q

By maturity, epiphyseal plates fuse with bone, terminating bone growth. High androgen level in maturity enhances plate closure. Excess growth hormone can now stimulate bone growth only in width, thickening shafts and heads (acromegaly).

ACROMEGALY O'