Bone as a Tissue

- **osteology** – the study of bone
- **skeletal system** - composed of bones, cartilages, and ligaments
  - form strong flexible framework of the body
  - **cartilage** – forms before most bones
    - covers many joint surfaces of mature bone
  - **ligaments** – hold bones together at the joints
  - **tendons** – attach muscle to bone

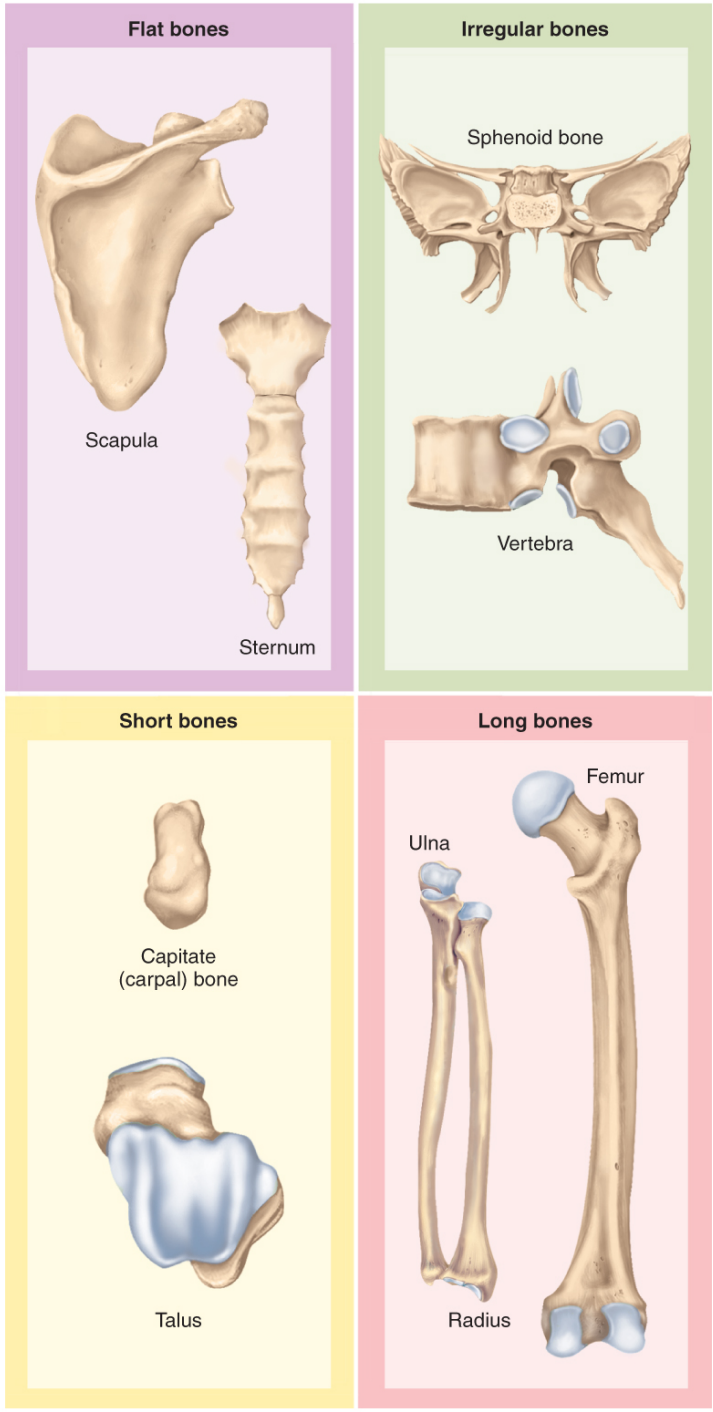
Functions of the Skeleton

- **support**
- **protection**
- **movement**
- **electrolyte balance** – calcium and phosphate ions
- **acid-base balance** – buffers blood against excessive pH changes
- **blood formation** – red bone marrow is the chief producer of blood cells

Bones and Osseous Tissue

- **bone** (osseous tissue) - connective tissue with the matrix hardened by calcium phosphate and other minerals
- **mineralization** or **calcification** – the hardening process of bone
- individual bones consist of bone tissue, bone marrow, cartilage, adipose tissue, nervous tissue, and fibrous connective tissue
- continually remodels itself and interacts physiologically with all of the other organ systems of the body
- permeated with nerves and blood vessels, sensitive to metabolic activity

Shapes of Bones



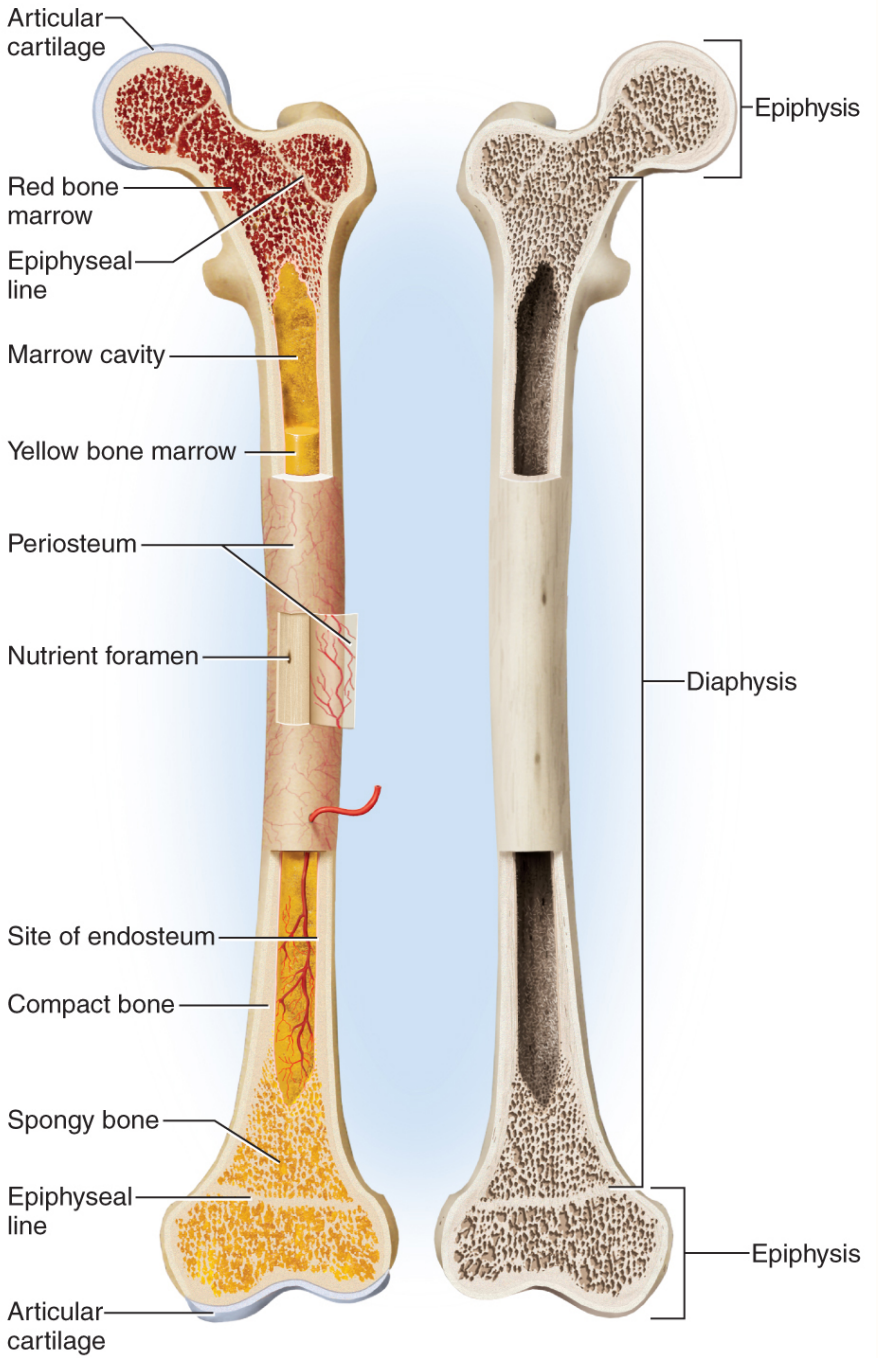
General Features of Bones

- **compact (dense) bone** – outer shell of long bone
- **diaphysis** (shaft) - cylinder of compact bone to provide leverage
- **medullary cavity** (marrow cavity) - space in the diaphysis of a long bone that contains bone marrow
- **epiphyses** - enlarged ends of a long bone
  - enlarged to strengthen joint and attach ligaments and tendons
- **spongy bone** covered by more durable compact bone
  - spongy bone found in ends of long bones, and the middle of nearly all others
- **articular cartilage** – a layer of hyaline cartilage that covers the joint surface where one bone meets another
  - allows joint to move more freely and relatively friction free
- **nutrient foramina** – minute holes in the bone surface that allows blood vessels to penetrate

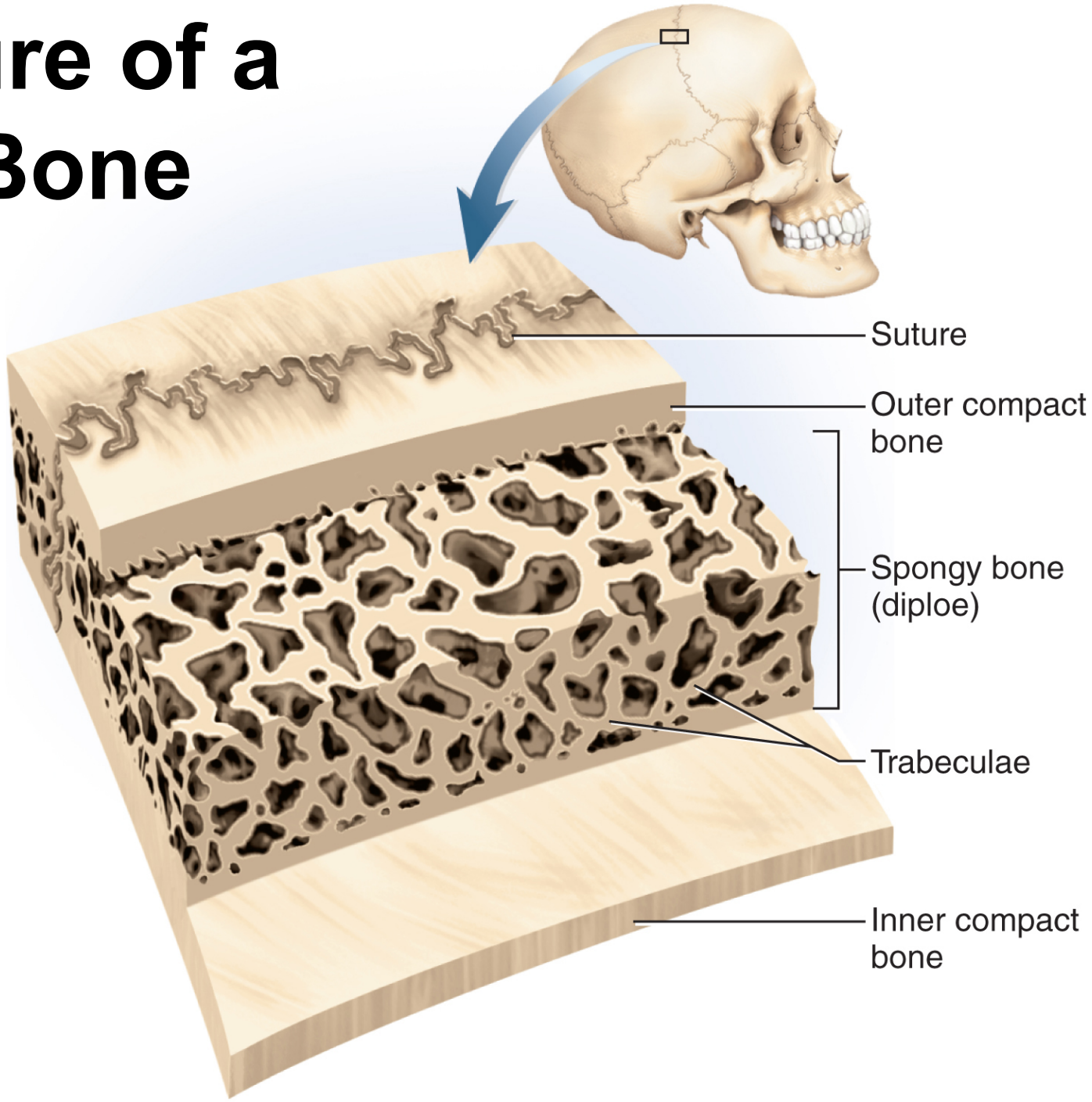
General Features of Bones

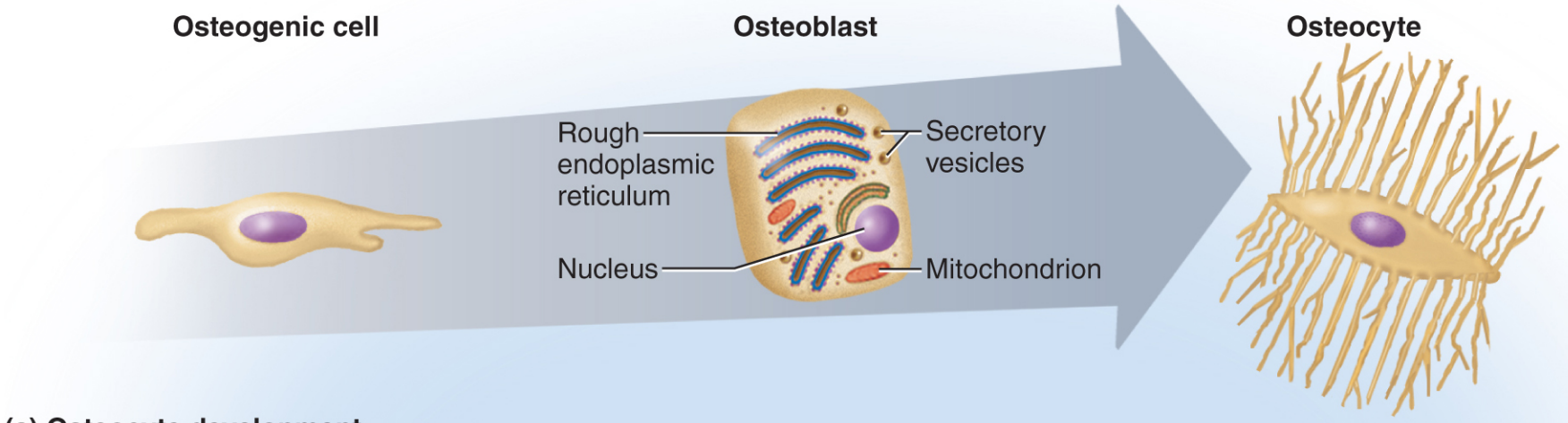
- **periosteum** – external sheath that covers bone except where there is articular cartilage
  - **outer fibrous layer** of collagen
    - strong attachment and continuity from muscle to tendon to bone
  - **inner osteogenic layer** of bone forming cells
    - important to growth of bone and healing of fractures
- **endosteum** – thin layer of reticular connective tissue lining marrow cavity
  - has cells that dissolve osseous tissue and others that deposit it
- **epiphyseal plate (growth plate)** – area of **hyaline cartilage** that separates the marrow spaces of the epiphysis and diaphysis
  - enables growth in length
  - **epiphyseal line** – in adults, a bony scar that marks where growth plate used to be

Structure of a Long Bone

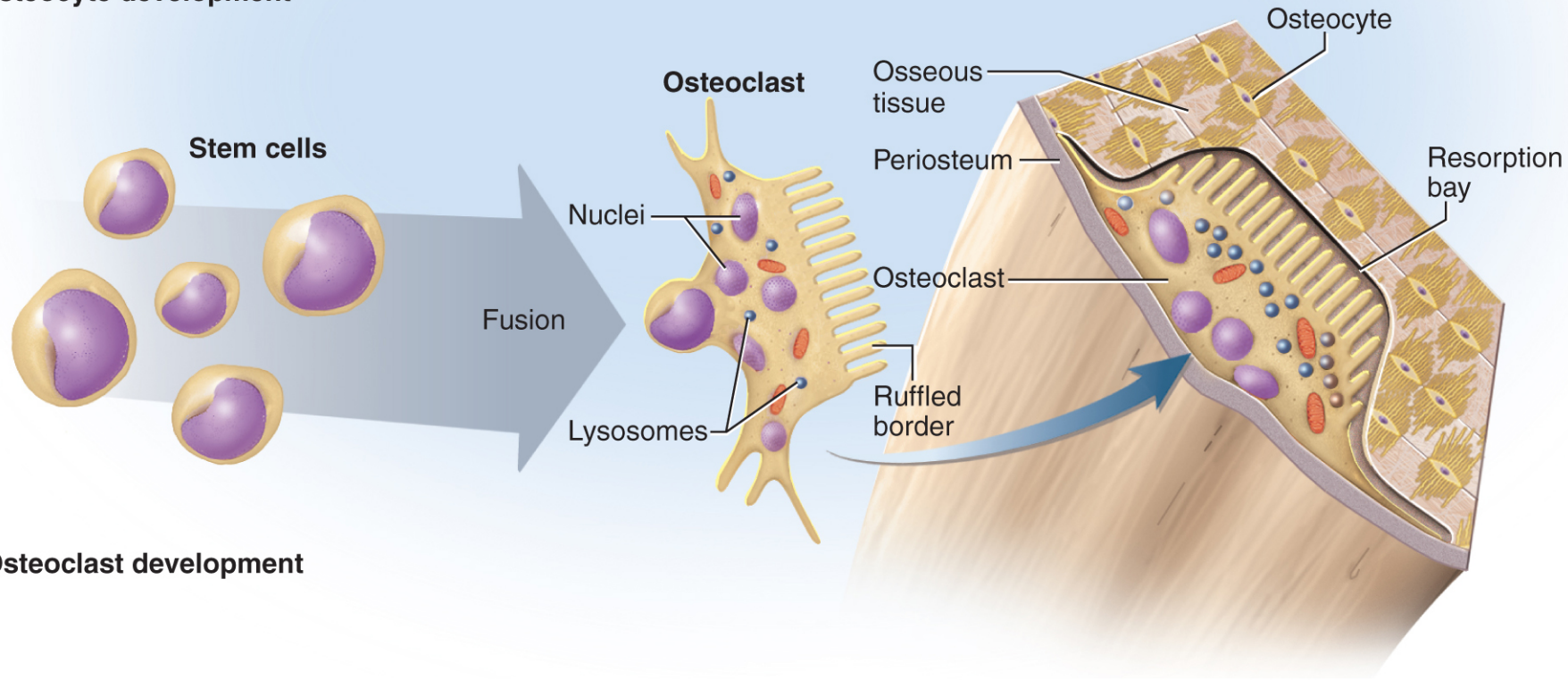


Structure of a Flat Bone





(a) Osteocyte development



(b) Osteoclast development

Osseous Cells

- **osteogenic cells**
  - stem cells found in endosteum, periosteum, and in central canals
  - multiply continuously to produce new osteoblasts
- **Osteoblasts**
  - bone forming cells
  - single layer of cells under endosteum and periosteum
- **Osteocytes**
  - former osteoblasts trapped in the matrix they have deposited
  - **lacunae** – tiny cavities where osteocytes reside
  - **canaliculi** – little channels that connect lacunae
  - some osteocytes reabsorb bone matrix while others deposit it

Osseous Cells

- **osteoclasts** – bone-dissolving cells found on the bone surface
  - **ruffled border –** side facing bone surface
    - several deep infoldings of the plasma membrane which increases surface area and resorption efficiency
  - **resorption bays** – pits on surface of bone where osteoclasts reside
  - **remodeling** – results from combined action of the bone-dissolving osteoclasts and the bone-depositing osteoblasts

The Matrix

- **organic matter** – synthesized by osteoblasts
  - collagen, carbohydrate – protein complexes, such as glycosaminoglycans, proteoglycans, and glycoproteins
- **inorganic matter**
  - 85% hydroxyapatite (crystallized calcium phosphate salt)
  - 10% calcium carbonate
  - other minerals (fluoride, sodium, potassium, magnesium)
- bone is **a composite** – combination of two basic structural materials, a ceramic and a polymer
- **rickets** – soft bones due to deficiency of calcium salts
- **osteogenesis imperfecta** or brittle bone disease – excessively brittle bones due to lack of protein, collagen

Histology of Compact and Spongy Bone

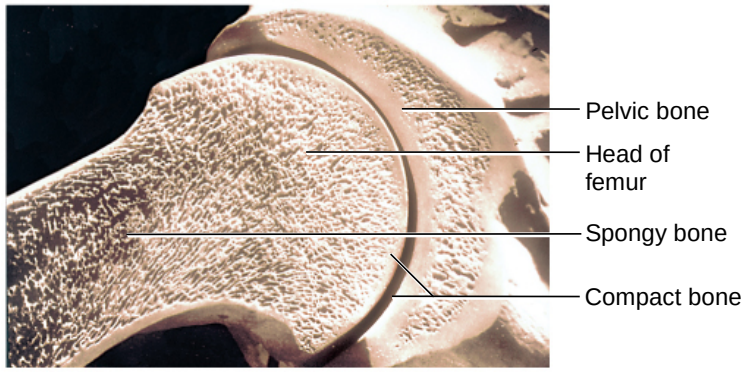


Figure 7.5a

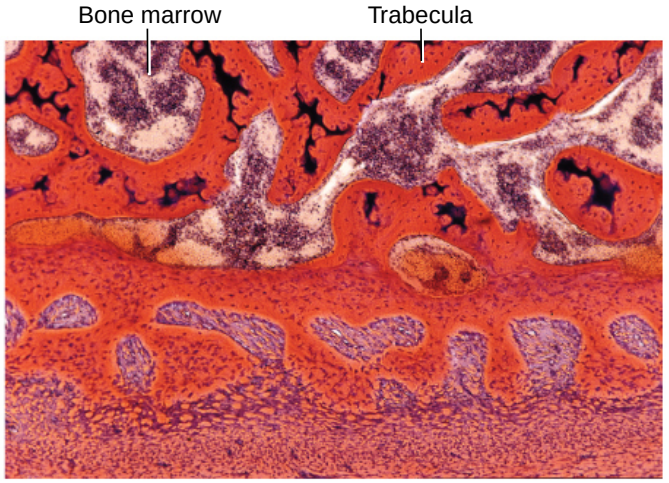


Figure 7.5c

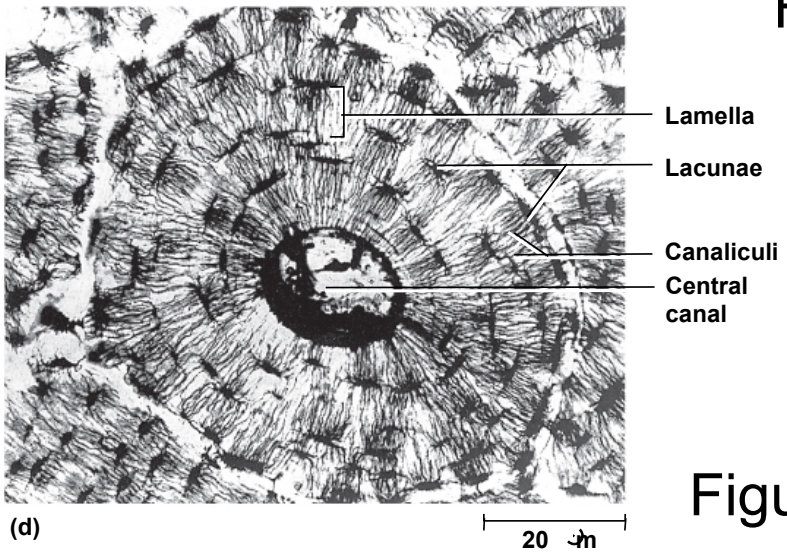


Figure 7.5d

Compact Bone

- **osteon (haversian system)** – the basic structural unit of compact bone
  - formed by a **central canal** and its **concentric lamella** connected to each other by **canaliculi**
  - **perforating (Volkmann) canals** are transverse or diagonal passages along the length of the osteon
  - **collagen fibers** "corkscrew" down the matrix of the lamella giving it a helical arrangement
  - helices coil in one direction in one lamella and in the opposite direction in the next lamella for added strength
  - **nutrient foramina** – on the surface of bone tissue that allow blood vessels and nerves to enter the bone
    - open into the perforating canals that cross the matrix and feed into the central canals
    - innermost osteocytes near central canal receive nutrients and pass them along through their gap junction to neighboring osteocytes
    - they also receive wastes from their neighbors and transfer them to the central canal maintaining a two-way flow of nutrients and waste
  - not all of the matrix is organized into osteons

Blood Vessels of Bone

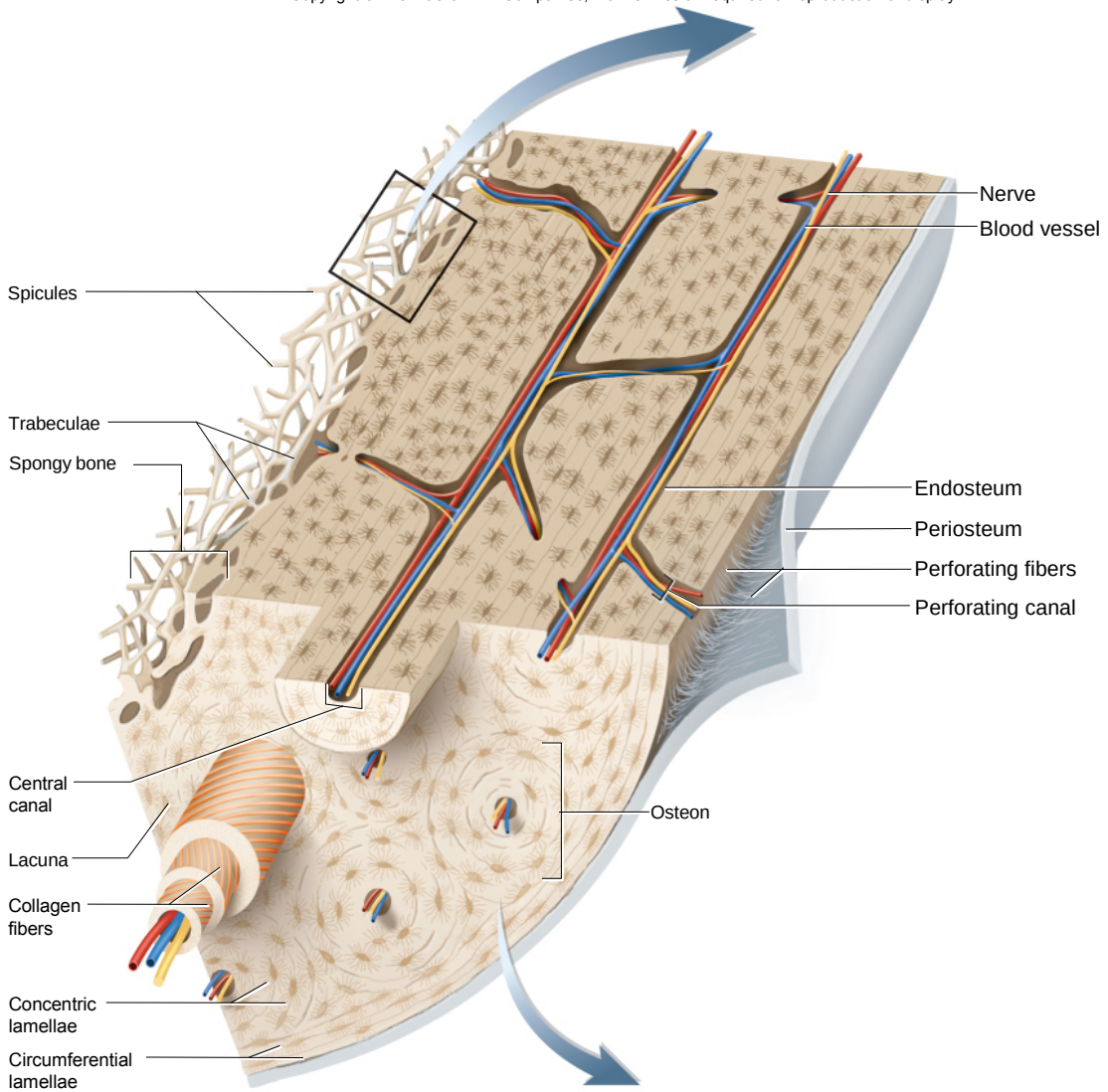


Figure 7.5b

- **nutrient foramina** – on bone surface
- **perforating (Volkmann's) canals** – transverse or diagonal canals
- **central canals** – vertical canals
- circumferential lamellae
- interstitial lamellae

Spongy Bone

- sponge-like appearance
- spongy bone consists of:
  - slivers of bone called **spicules**
  - thin plates of bone called **trabeculae**
  - spaces filled with **red bone marrow**
- few osteons and no central canals
  - all osteocytes close to bone marrow
- provides strength with minimal weight
  - trabeculae develop along bone's **lines of stress**

Design of Spongy Bone

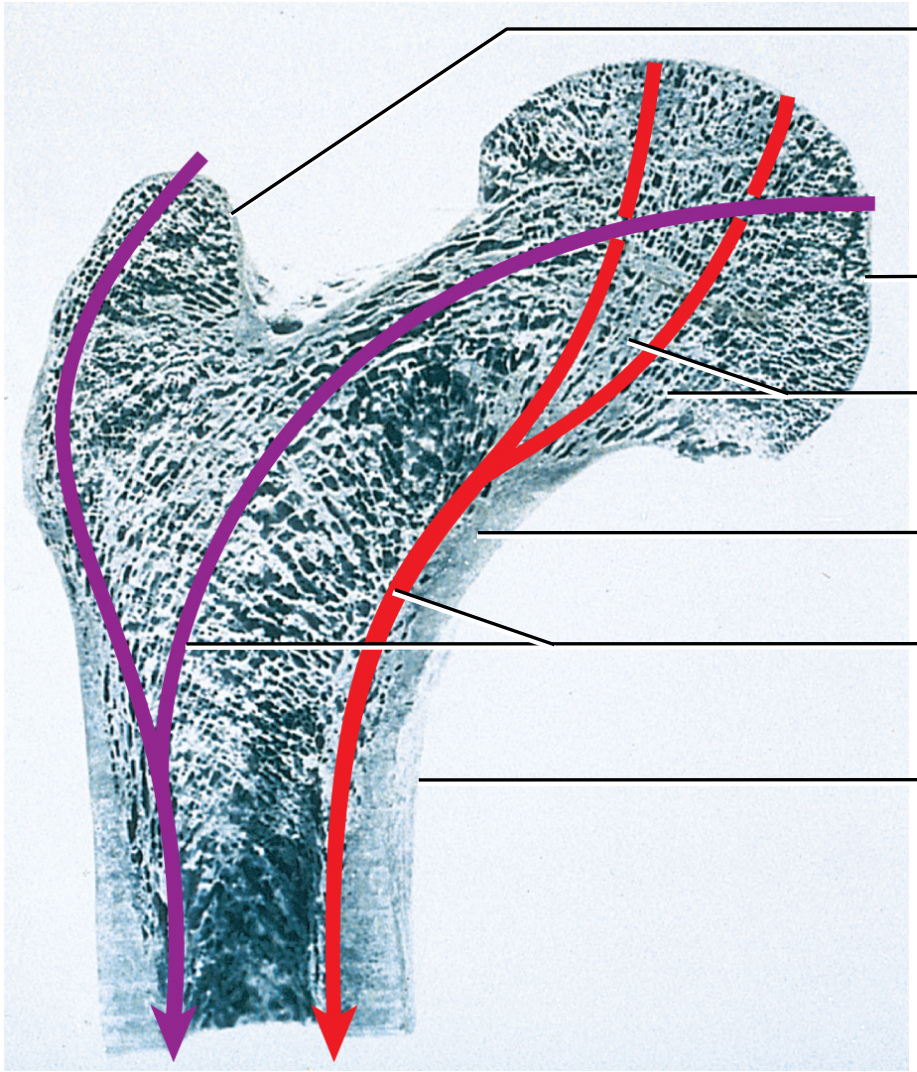


Figure 7.6

Bone Marrow

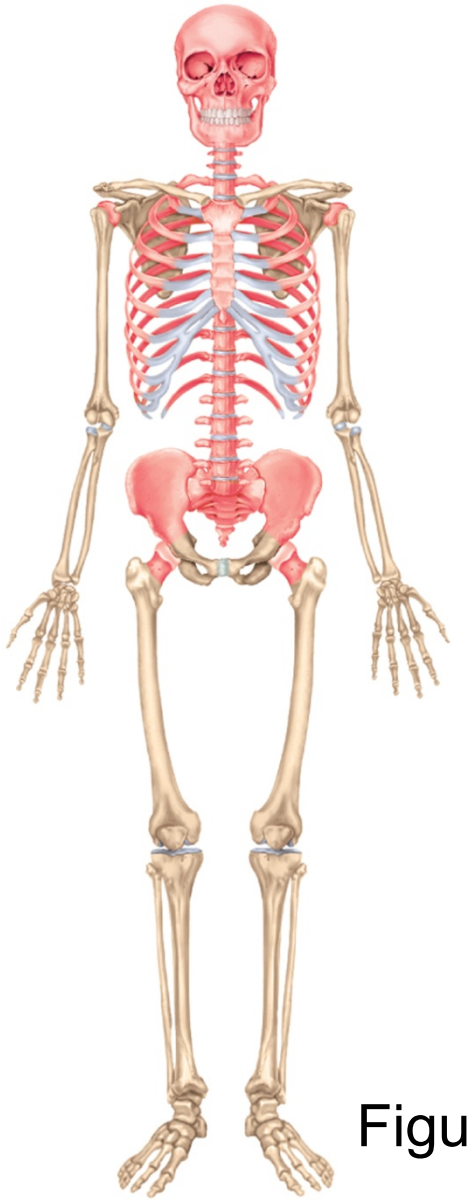


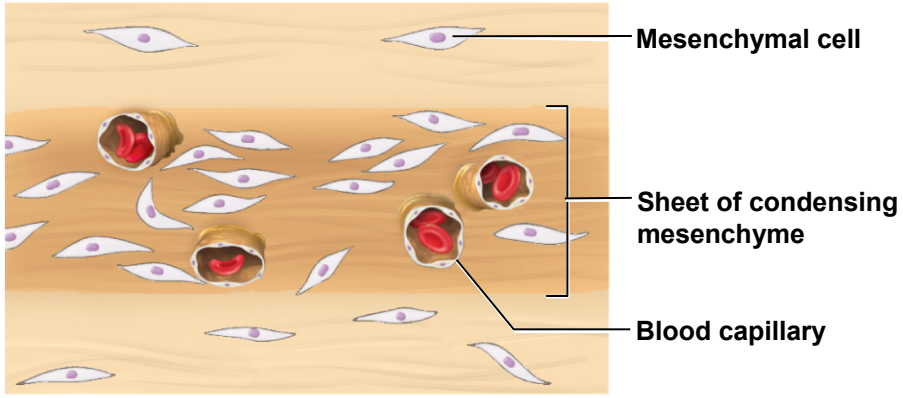
Figure 7.7

- **bone marrow** – general term for soft tissue that occupies the marrow cavity of a long bone and small spaces amid the trabeculae of spongy bone
- **red marrow (myeloid tissue)**
  - **hemopoietic tissue** - produces blood cells
  - in adults, found in **skull**, **vertebrae**, **ribs**, **sternum**, part of **pelvic girdle**, and **proximal heads of humerus and femur**
- **yellow marrow** found in adults
  - most red marrow turns into fatty yellow marrow
  - no longer produces blood

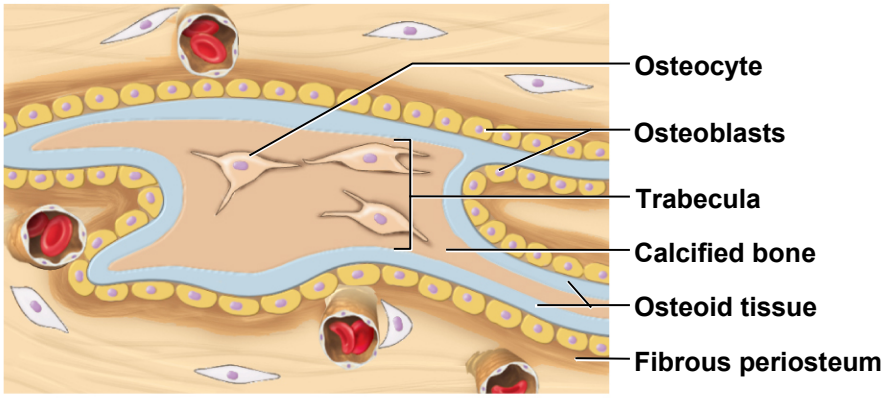
Ossification

- **intramembranous ossification**
  - produce the flat bones of the skull and most of the clavicle (collar bone)
  - develop within a fibrous sheet similar to epidermis of the skin (**dermal bones**)
- **endochondral ossification**
  - process in which bone develops from pre-existing cartilage model
  - beginning the 6th fetal week and ending in early 20's
  - most bones develop by this process

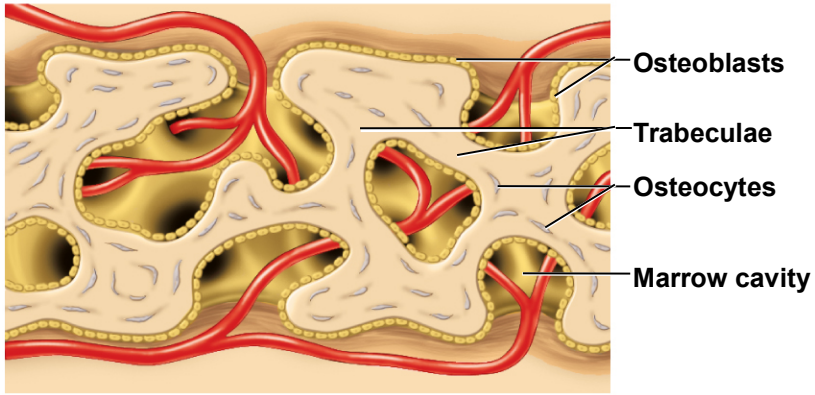
Intramembranous Ossification



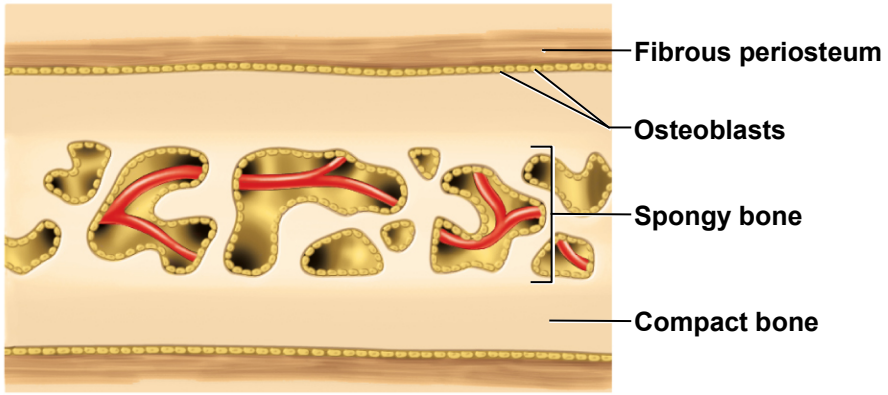
1 Condensation of mesenchyme into soft sheet permeated with blood capillaries



2 Deposition of osteoid tissue by osteoblasts on mesenchymal surface; entrapment of first osteocytes; formation of periosteum



3 Honeycomb of bony trabeculae formed by continued mineral deposition; creation of spongy bone

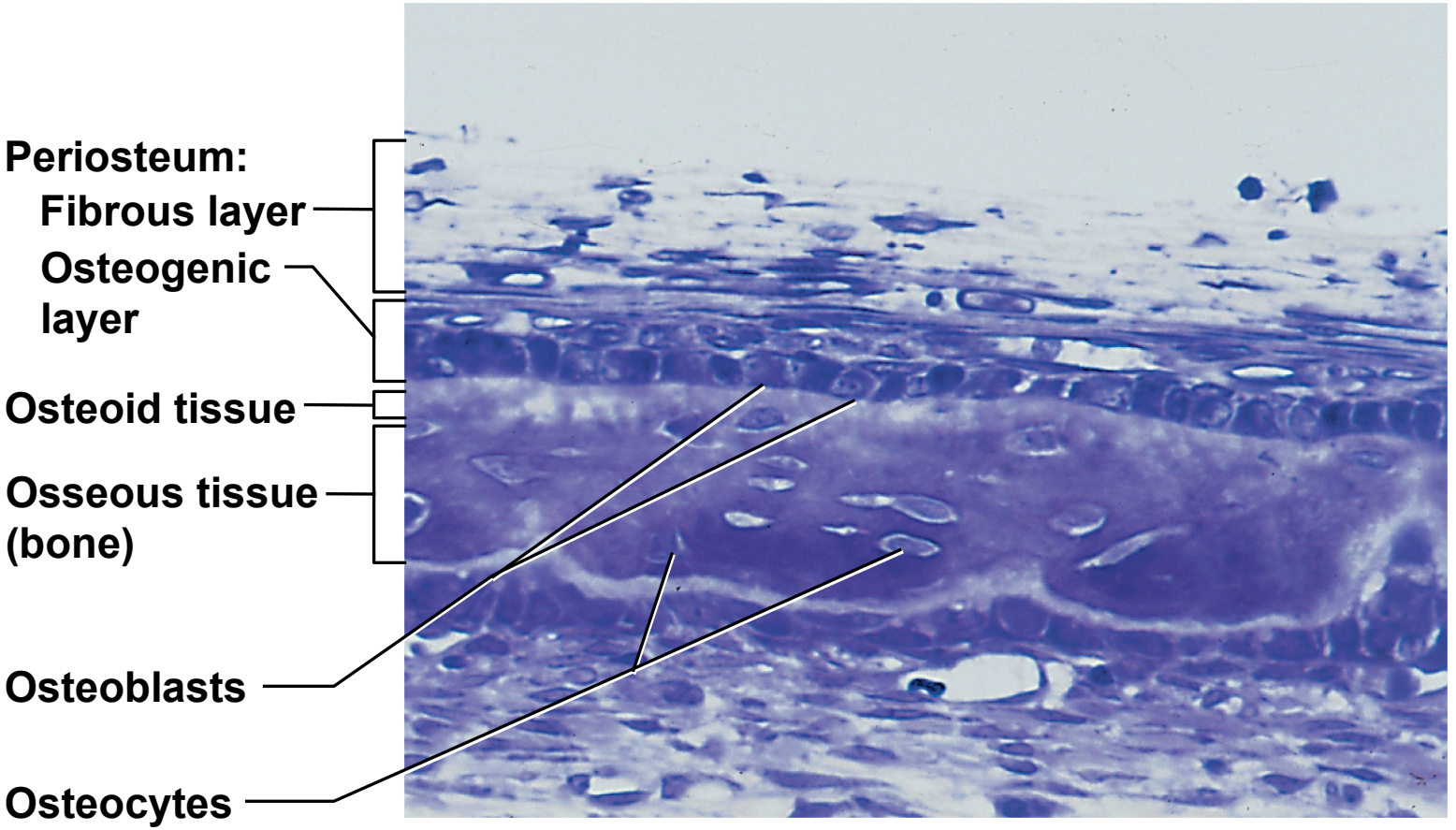


4 Surface bone filled in by bone deposition, converting spongy bone to compact bone. Persistence of spongy bone in the middle layer.

Figure 7.8

produces flat bones of skull and clavicle

Intramembranous Ossification

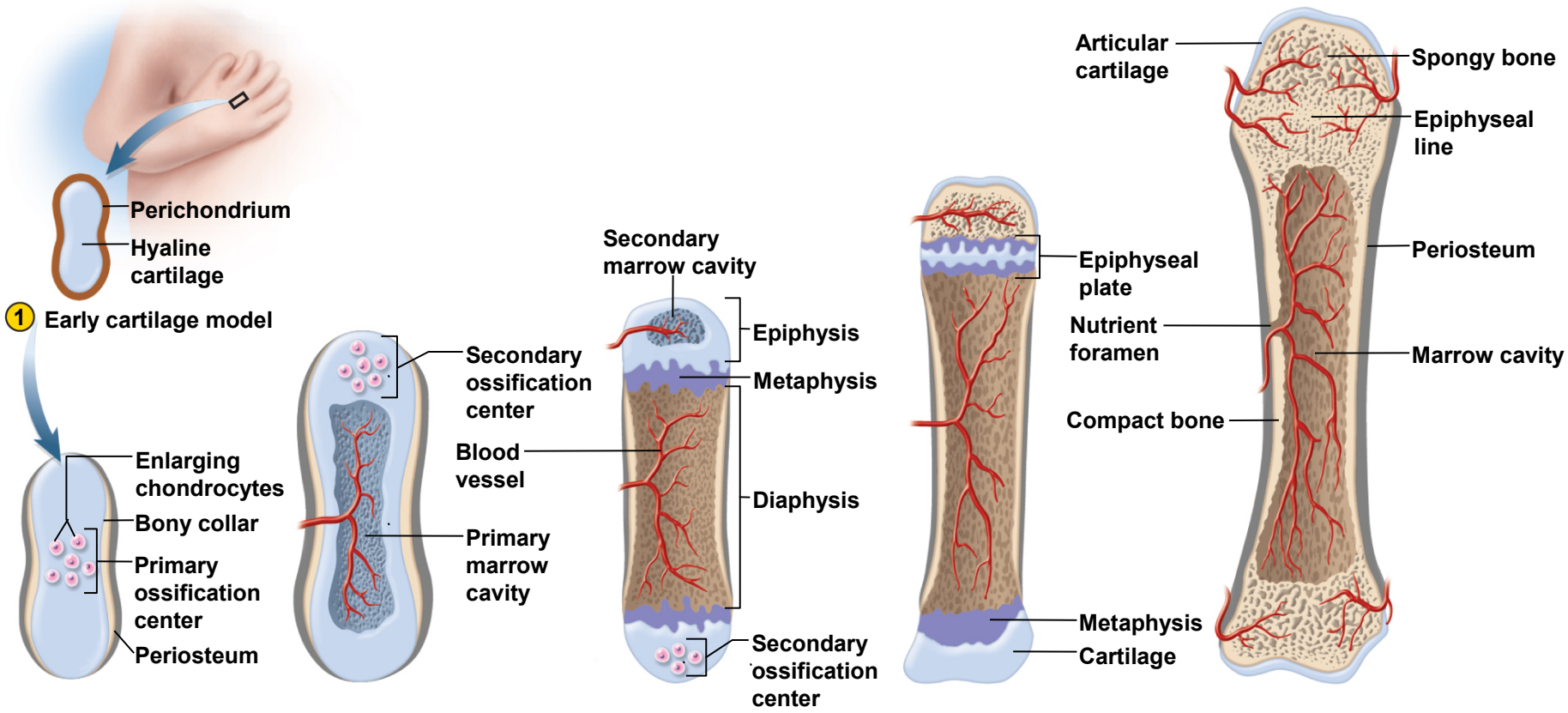


© Ken Saladin

Figure 7.9

note the periosteum and osteoblasts.

Stages of Endochondral Ossification



2 Formation of primary ossification center, bony collar, and periosteum

3 Vascular invasion, formation of primary marrow cavity, and appearance of secondary ossification center

4 Bone at birth, with enlarged primary marrow cavity and appearance of secondary marrow cavity in one epiphysis

5 Bone of child, with epiphyseal plate at distal end

6 Adult bone with a single marrow cavity and closed epiphyseal plate

Figure 7.10

Cartilaginous Epiphyseal Plates

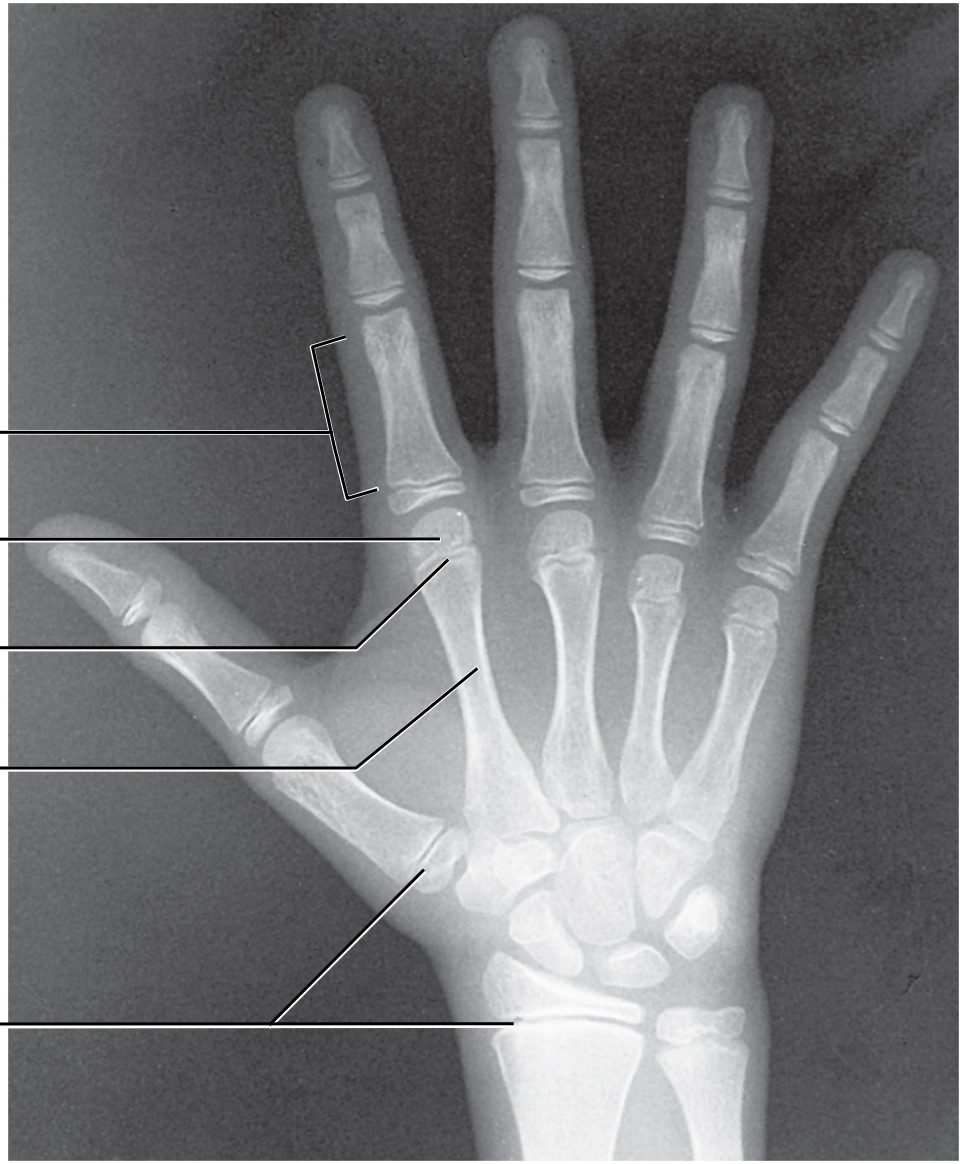


Figure 7.12

Courtesy of Utah Valley Regional Medical Center, Department of Radiology

Bone Growth and Remodeling

- **ossification** continues throughout life with the growth and remodeling of bones
- bones grow in two directions: **length** and **width**
- **bone elongation**
  - **epiphyseal plate –** a region of transition from cartilage to bone
    - functions as **growth zone** where the bones elongate
    - consists of typical hyaline cartilage in the middle
    - with a transition zone on each side where cartilage is being replaced by bone
    - **metaphysis** is the zone of transition facing the marrow cavity

Bone Growth and Remodeling

- **bone remodeling** occurs throughout life - 10% per year
  - repairs microfractures, releases minerals into blood, reshapes bones in response to use and disuse
  - **Wolff's law of bone** - architecture of bone determined by mechanical stresses placed on it and bones adapt to withstand those stresses
    - collaborative and precise action of osteoblasts and osteoclasts
    - bony processes grow larger in response to mechanical stress

Hormonal Control of Calcium

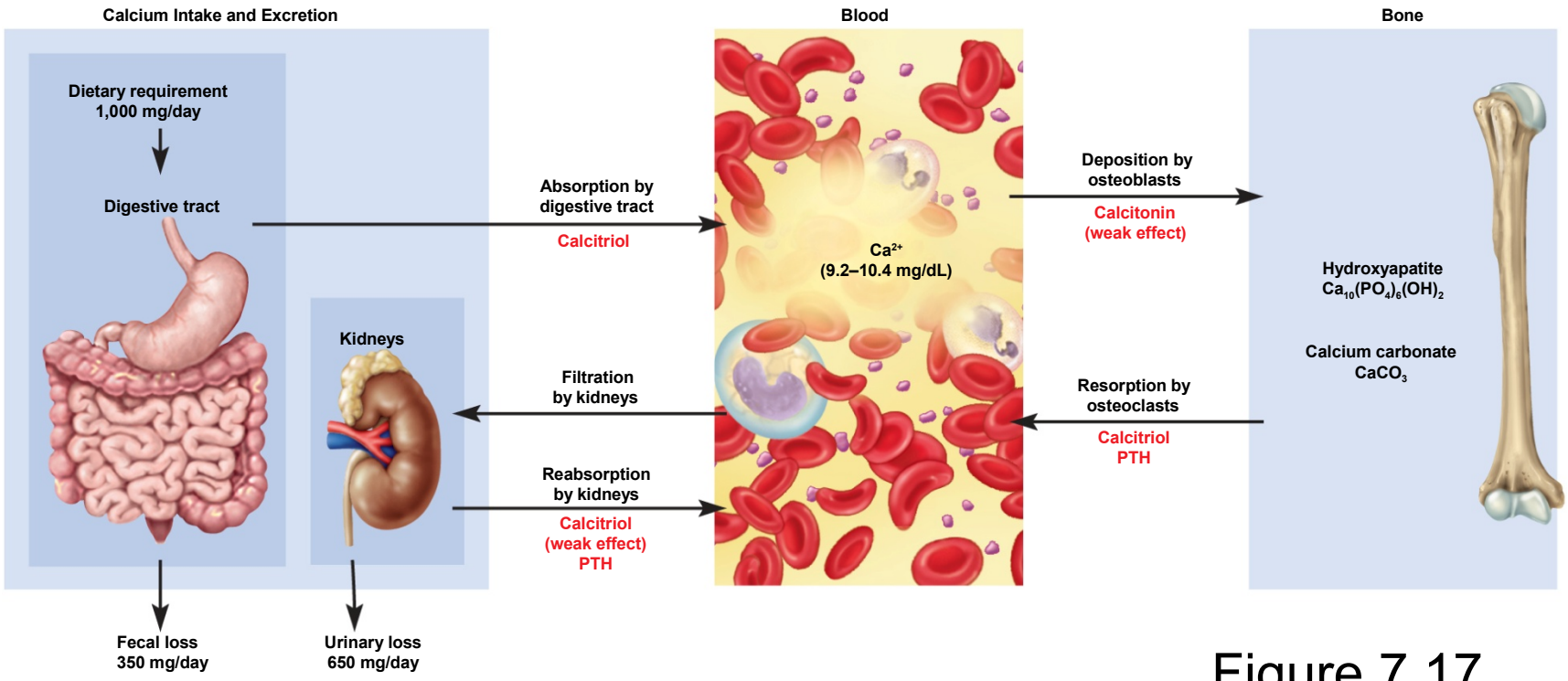
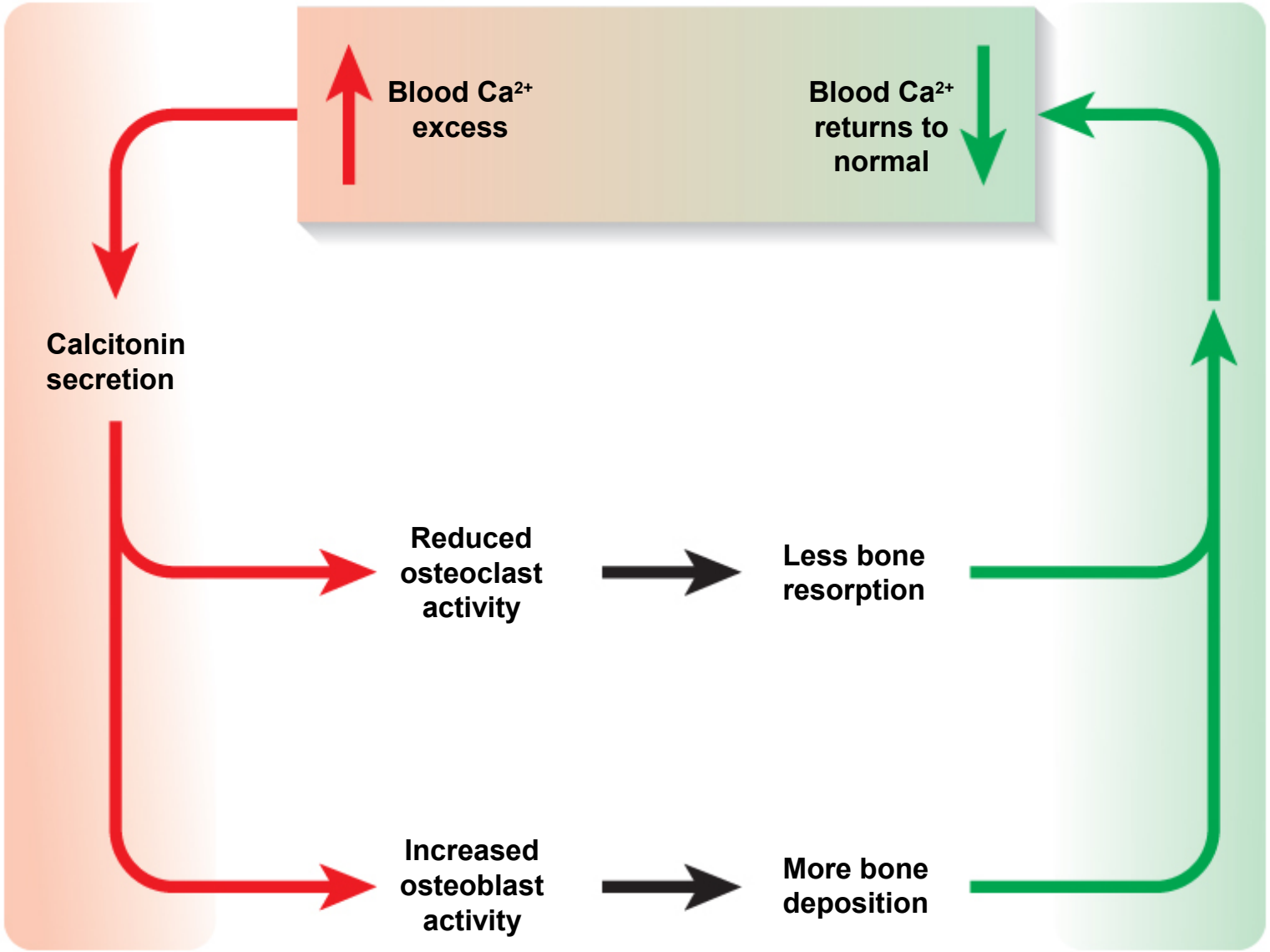


Figure 7.17

calcitriol, calcitonin, and PTH maintain normal blood calcium concentration

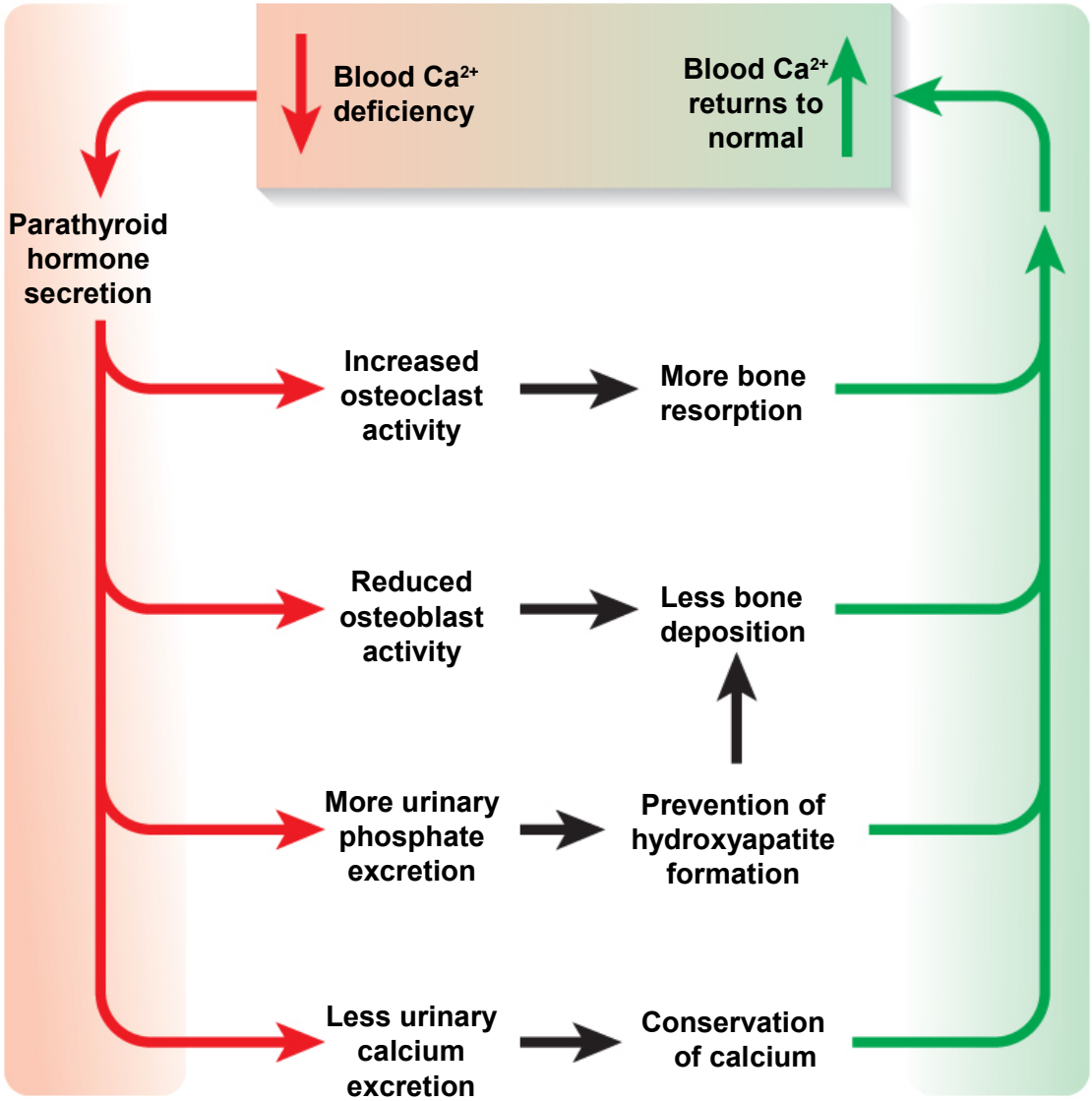
Correction for Hypercalcemia



(a) Correction for hypercalcemia

Figure 7.18a

Correction for Hypocalcemia



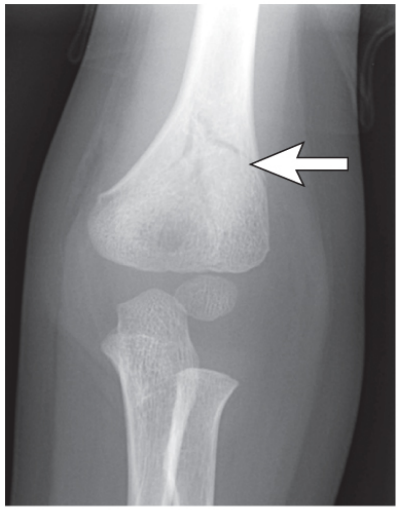
(b) Correction for hypocalcemia

Figure 7.18b

Phosphate Homeostasis

- calcitriol promotes its absorption by small intestine & promotes bone deposition
- PTH lowers blood phosphate level by promoting its urinary excretion

Types of Bone Fractures



(a) Nondisplaced

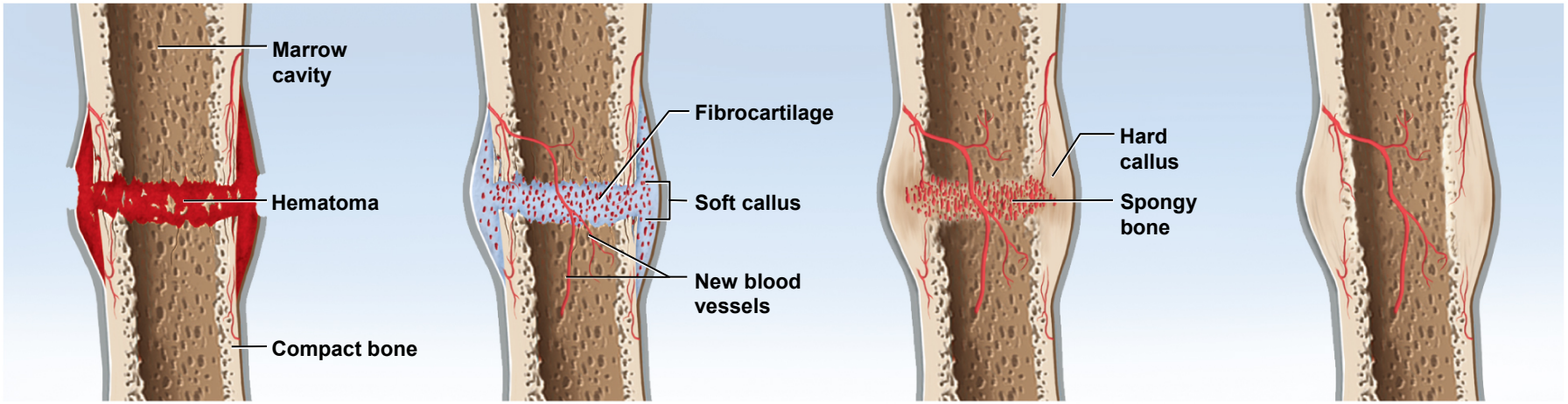
(c) Comminuted

(d) Greenstick

Figure 7.19

a: Custom Medical Stock Photo, Inc.; c: © Lester V. Bergman/Corbis; d: Custom Medical Stock Photo, Inc.

Healing of Fractures



1. **Hematoma formation**
   The hematoma is converted to granulation tissue by invasion of cells and blood capillaries.
2. **Soft callus formation**
   Deposition of collagen and fibrocartilage converts granulation tissue to a soft callus.
3. **Hard callus formation**
   Osteoblasts deposit a temporary bony collar around the fracture to unite the broken pieces while ossification occurs.
4. **Bone remodeling**
   Small bone fragments are removed by osteoclasts, while osteoblasts deposit spongy bone and then convert it to compact bone.

Figure 7.20

Osteoporosis

- **osteoporosis** – the most common bone disease
  - severe loss of bone density
- bones lose mass and become brittle due to loss of organic matrix and minerals
  - affects spongy bone the most since it is the most metabolically active
  - subject to pathological fractures of hip, wrist and vertebral column
- postmenopausal white women at greatest risk
  - begin to lose bone mass as early as 35 yoa
    - by age 70, average loss is 30% of bone mass

Osteoporosis

- estrogen maintains density in both sexes inhibits resorption by osteoclasts
  - testes and adrenals produce estrogen in men
  - in women, rapid bone loss after menopause since estrogen blood level drops

Spinal Osteoporosis

(a)

(b)

a: © Michael Klein/Peter Arnold, Inc.; b: © Dr. P. Marzzi/Photo Researchers, Inc.

Figure 7.22 a-b