AN INTRODUCTION TO SKELETAL SYSTEM

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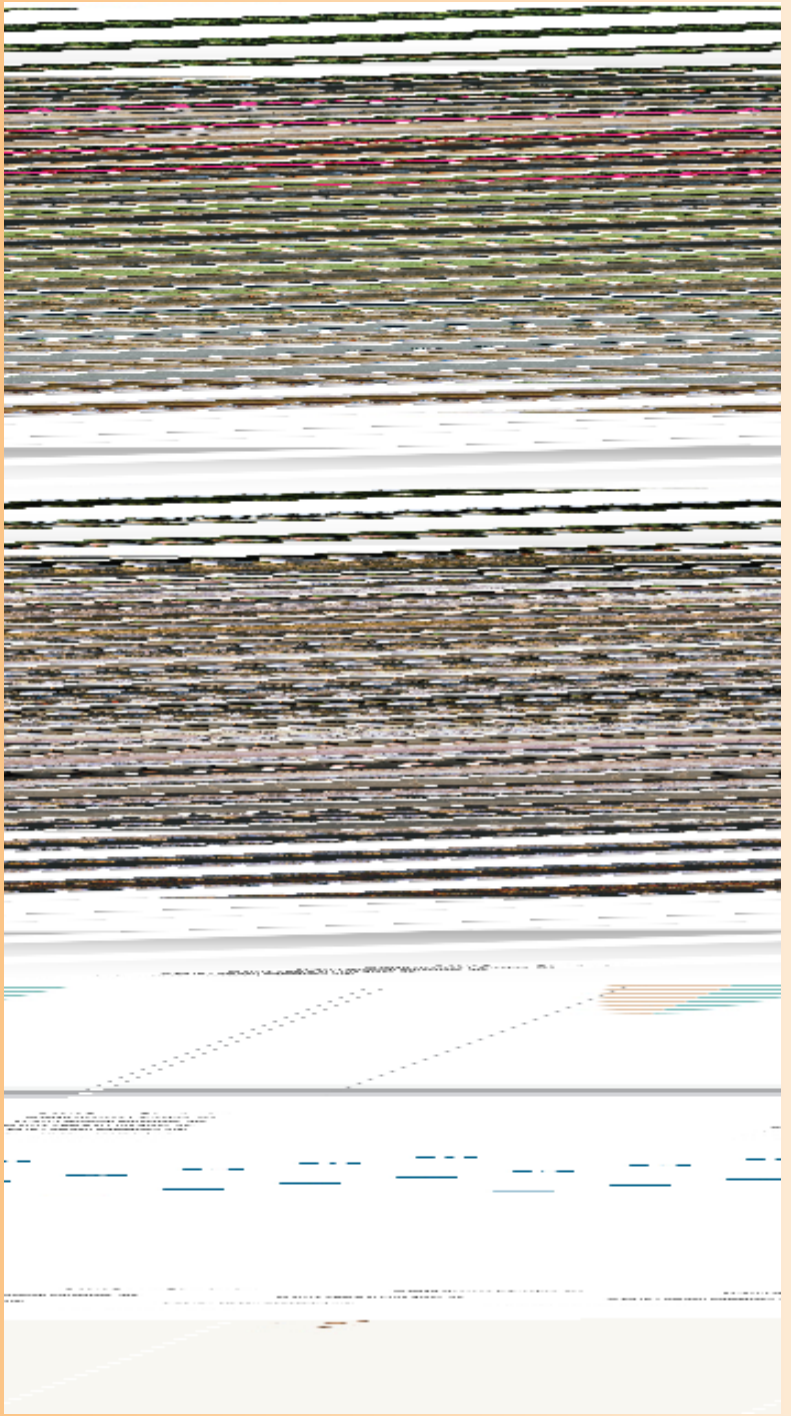
THE SKELETON



An Introduction to the Skeletal System

- Learning Outcomes
  - 6-1 Describe the primary functions of the skeletal system.
  - 6-2 Classify bones according to shape and internal organization, giving examples of each type, and explain the functional significance of each of the major types of bone markings.
  - 6-3 Identify the cell types in bone, and list their major functions.

An Introduction to the Skeletal System

- Learning Outcomes
  - 6-4 Compare the structures and functions of compact bone and spongy bone.
  - 6-5 Compare the mechanisms of endochondral ossification and intramembranous ossification.
  - 6-6 Describe the remodeling and homeostatic mechanisms of the skeletal system.
  - 6-7 Discuss the effects of exercise, hormones, and nutrition on bone development and on the skeletal system.

An Introduction to the Skeletal System

- Learning Outcomes
  - 6-8 Explain the role of calcium as it relates to the skeletal system.
  - 6-9 Describe the types of fractures, and explain how fractures heal.
  - 6-10 Summarize the effects of the aging process on the skeletal system.

An Introduction to the Skeletal System

- The Skeletal System
  - Includes:
    - Bones of the skeleton
    - Cartilages, ligaments, and connective tissues

6-1 Functions of the Skeletal System

- Five Primary Functions of the Skeletal System
  1. Support
  2. Storage of Minerals (calcium) and Lipids (yellow marrow)
  3. Blood Cell Production (red marrow)
  4. Protection
  5. Leverage (force of motion)

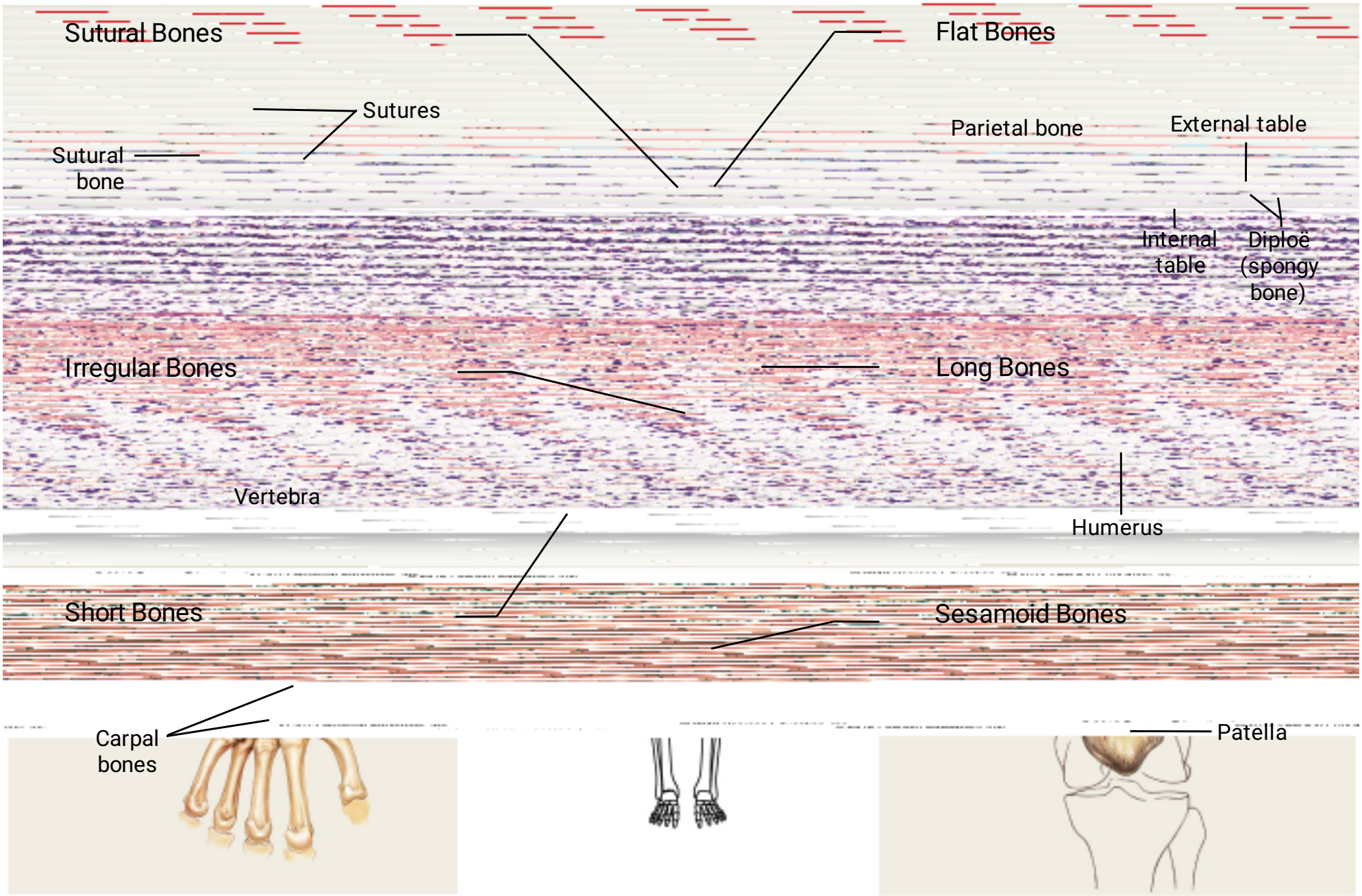
6-2 Classification of Bones

- Bones
  - Are classified by:
    - Shape
    - Internal tissue organization
    - Bone markings (surface features; marks)

6-2 Classification of Bones

- Six Bone Shapes
  1. Sutural bones
  2. Irregular bones
  3. Short bones
  4. Flat bones
  5. Long bones
  6. Sesamoid bones

Figure 6-1 A Classification of Bones by Shape



6-2 Classification of Bones

- Sutural Bones
  - Small, irregular bones
  - Found between the flat bones of the skull

- Irregular Bones
  - Have complex shapes
  - Examples: spinal vertebrae, pelvic bones

Figure 6-1a A Classification of Bones by Shape

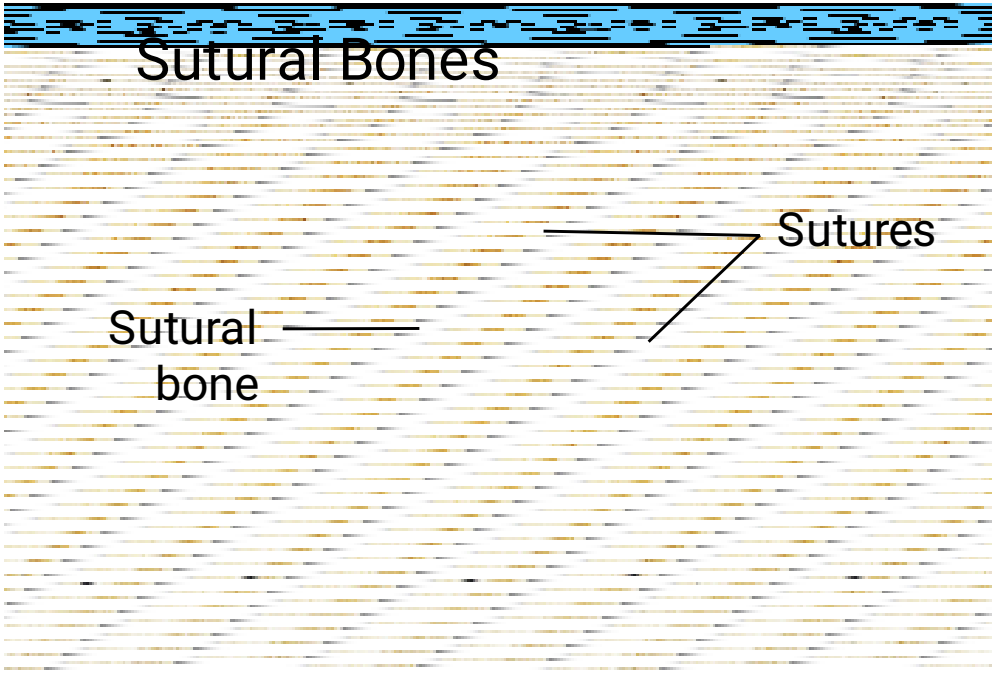


Figure 6-1b A Classification of Bones by Shape

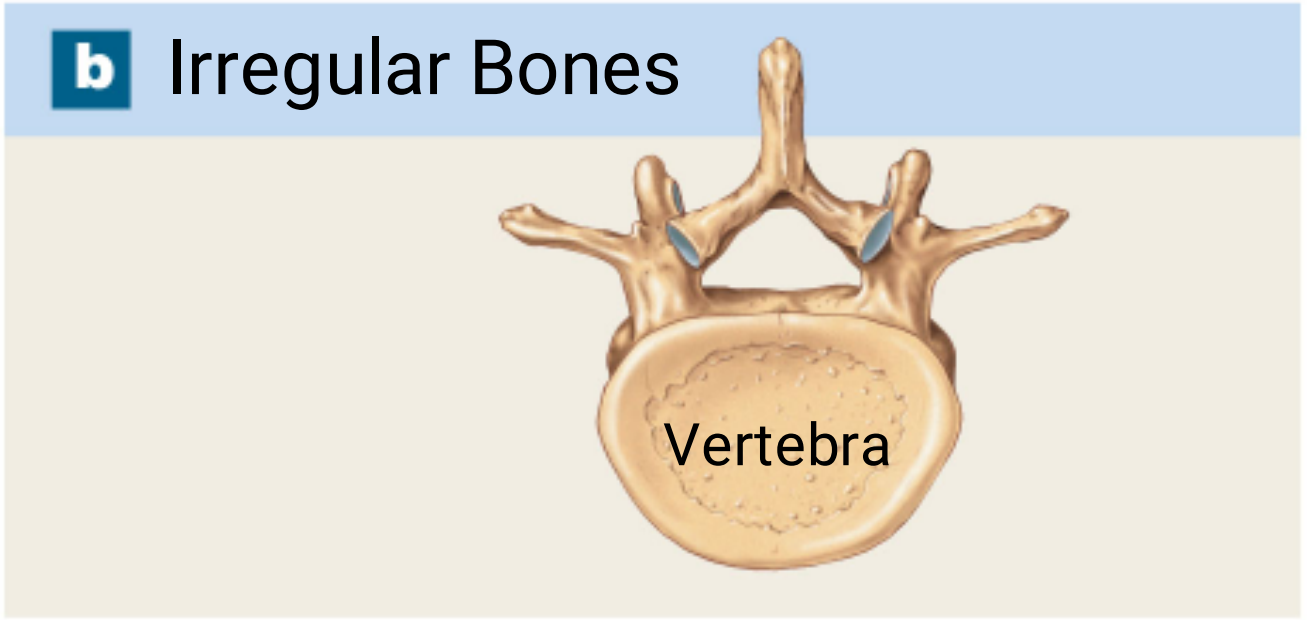
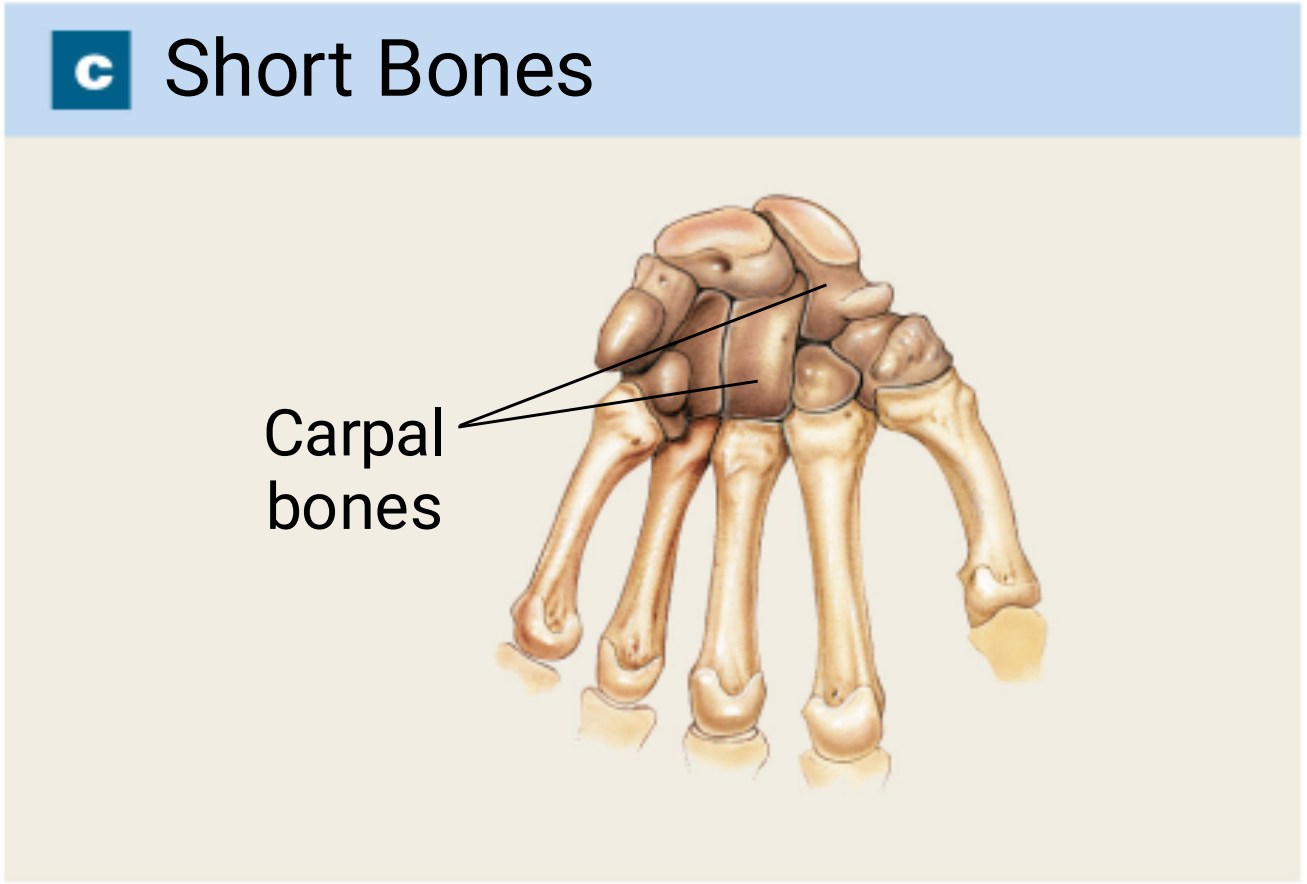


Figure 6-1c A Classification of Bones by Shape



6-2 Classification of Bones

- Short Bones
  - Small and thick
  - Examples: ankle and wrist bones
- Flat Bones
  - Thin with parallel surfaces
  - Found in the skull, sternum, ribs, and scapulae

6-2 Classification of Bones

- Long Bones
  - Long and thin
  - Found in arms, legs, hands, feet, fingers, and toes

- Sesamoid Bones
  - Small and flat
  - Develop inside tendons near joints of knees, hands, and feet

Figure 6-1d A Classification of Bones by Shape

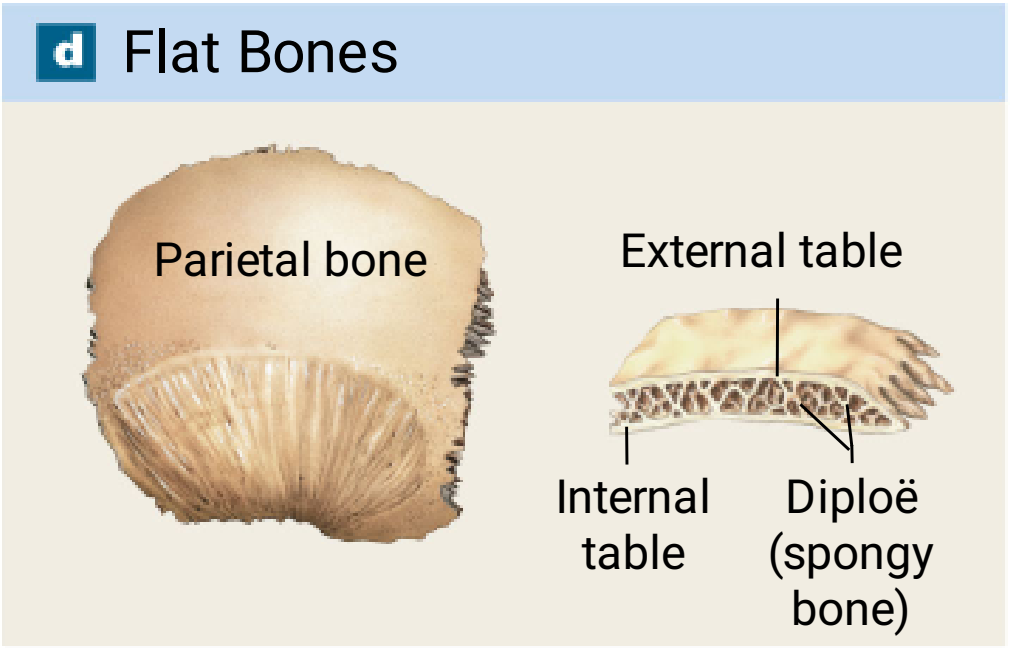


Figure 6-1e A Classification of Bones by Shape

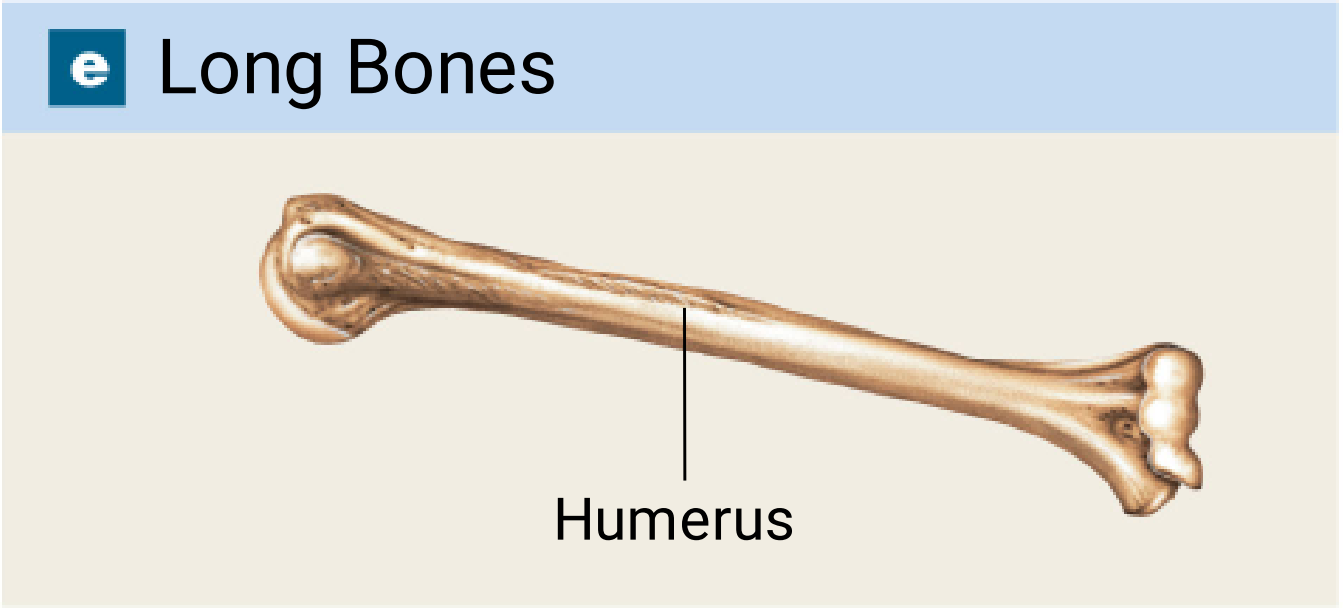
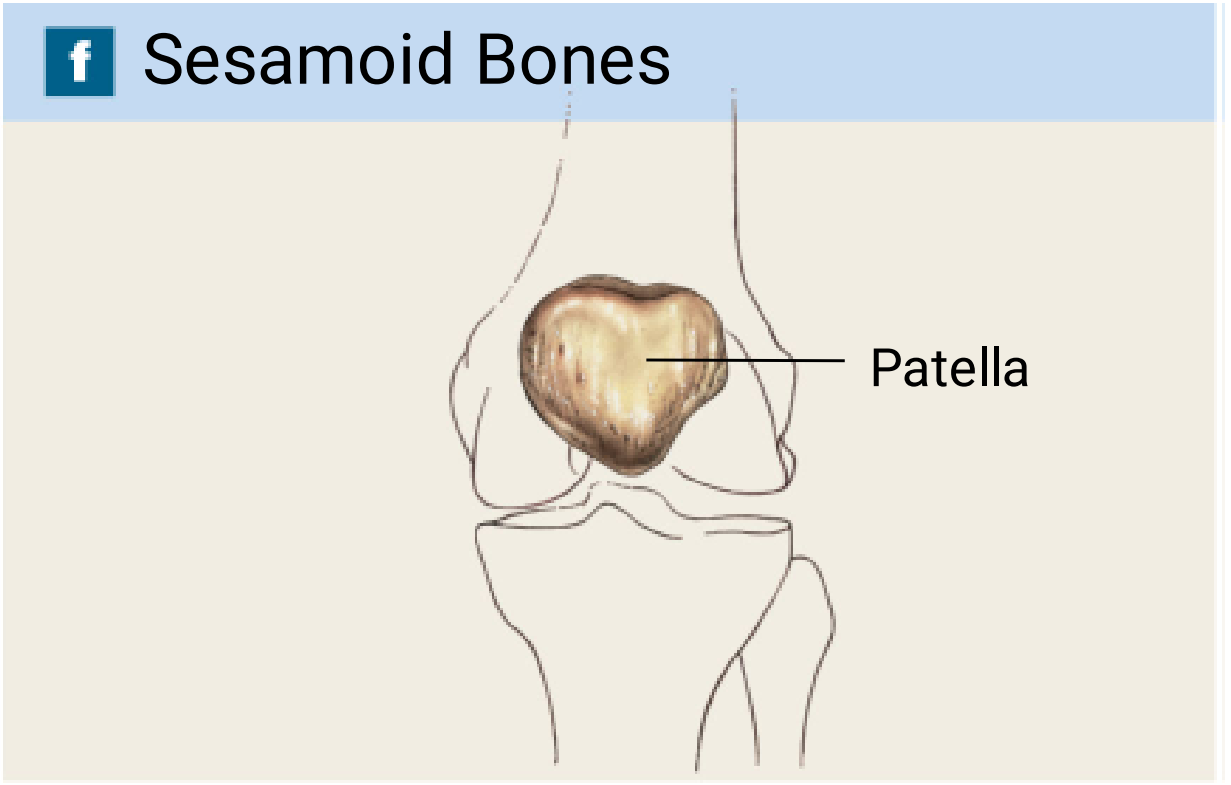


Figure 6-1f A Classification of Bones by Shape



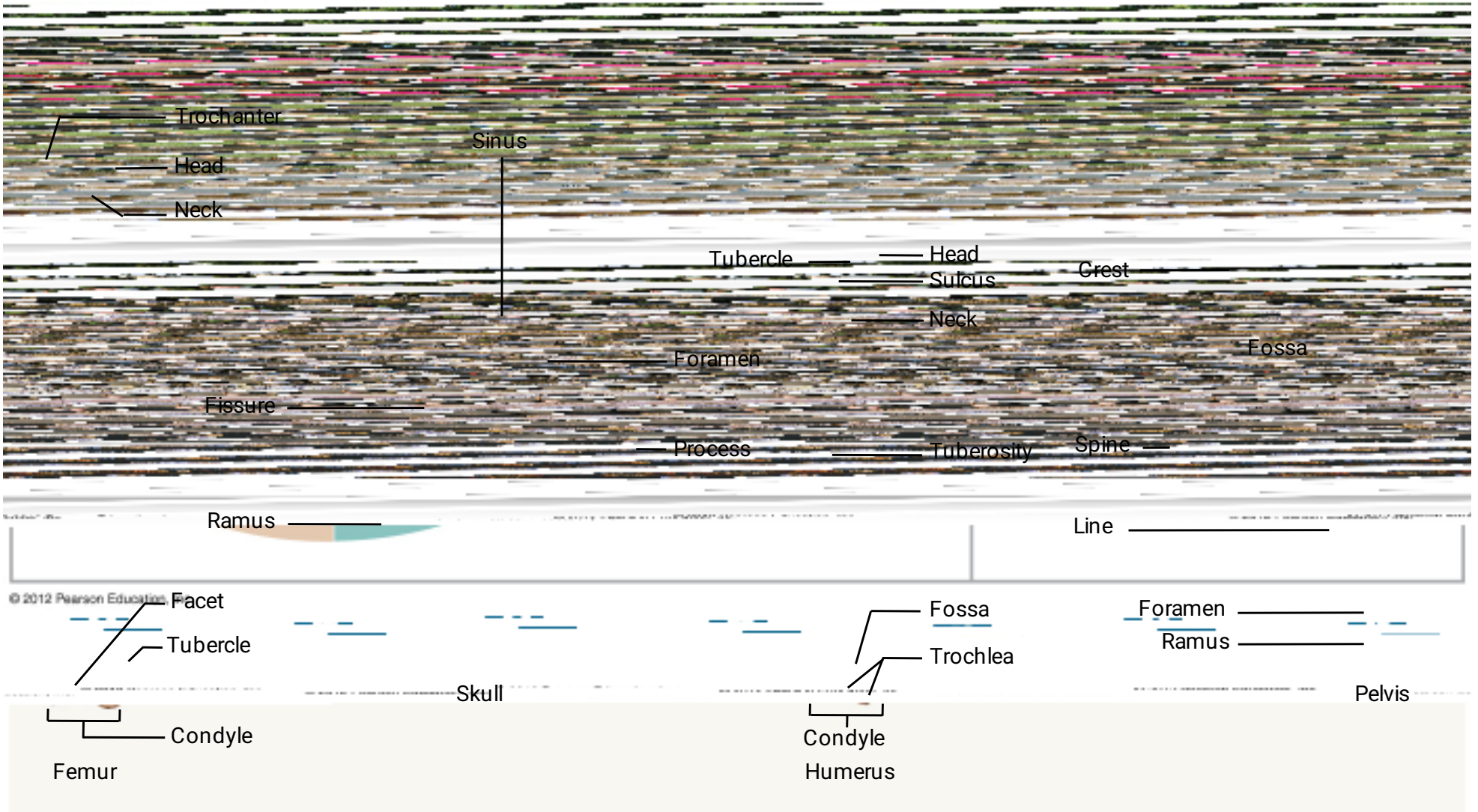
6-2 Classification of Bones

- Bone Markings
  - Depressions or grooves
    - Along bone surface
  - Elevations or projections
    - Where tendons and ligaments attach
    - At articulations with other bones
  - Tunnels
    - Where blood and nerves enter bone

Table 6–1 An Introduction to Bone Markings

General Description	Anatomical Term	Definition
Elevations and projections	**Process**	Any projection or bump
	Ramus	An extension of a bone making an angle with the rest of the structure
Processes formed where tendons or ligaments attach	**Trochanter**	A large, rough projection
	Tuberosity	A smaller, rough projection
	Tubercle	A small, rounded projection
	Crest	A prominent ridge
	Line	A low ridge
	Spine	A pointed or narrow process
Processes formed for articulation with adjacent bones	**Head**	The expanded articular end of an epiphysis, separated from the shaft by a neck
	Neck	A narrow connection between the epiphysis and the diaphysis
	Condyle	A smooth, rounded articular process
	Trochlea	A smooth, grooved articular process shaped like a pulley
	Facet	A small, flat articular surface
Depressions	**Fossa**	A shallow depression
	Sulcus	A narrow groove
Openings	**Foramen**	A rounded passageway for blood vessels or nerves
	Canal	A duct or channel
	Meatus	A passageway through a bone
	Fissure	An elongated cleft or slit
	Sinus	A chamber within a bone, normally filled with air

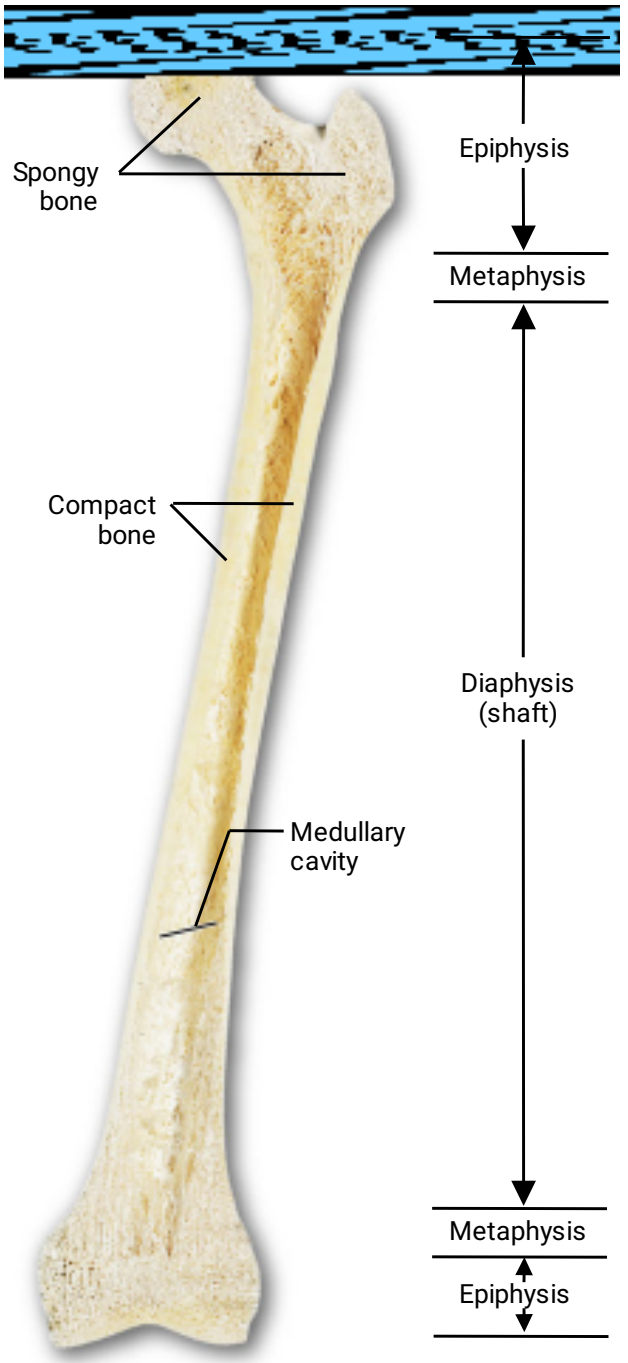
Table 6-1 An Introduction to Bone Markings



6-2 Classification of Bones

- Structure of a Long Bone
  - Diaphysis
    - The shaft
    - A heavy wall of compact bone, or dense bone
    - A central space called medullary (marrow) cavity
  - Epiphysis
    - Wide part at each end
    - Articulation with other bones
    - Mostly spongy (cancellous) bone
    - Covered with compact bone (cortex)
  - Metaphysis
    - Where diaphysis and epiphysis meet

Figure 6-2a Bone Structure

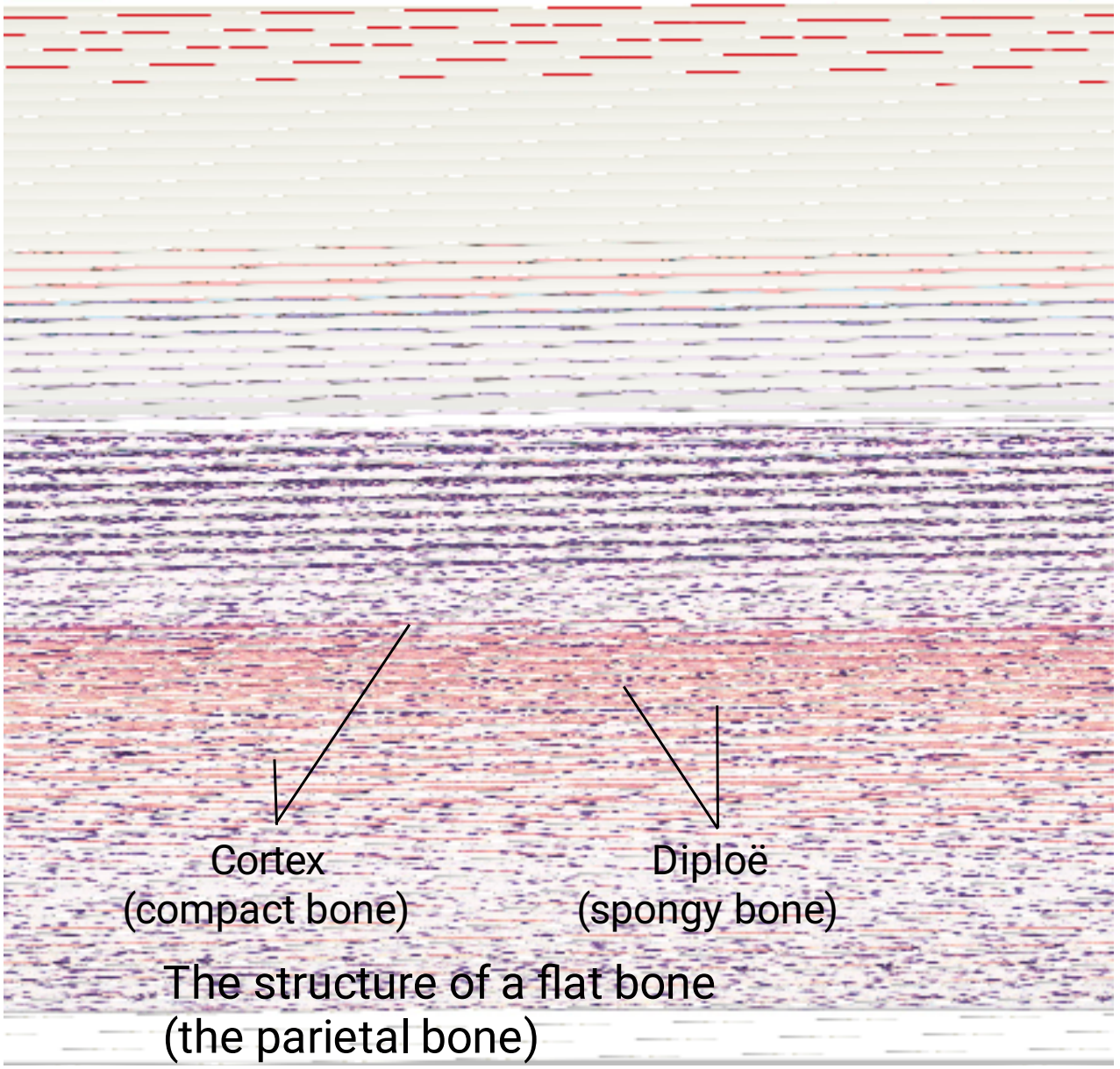


a The structure of a representative long bone (the femur) in longitudinal section

6-2 Classification of Bones

- Structure of a Flat Bone
  - The parietal bone of the skull
  - Resembles a sandwich of spongy bone
  - Between two layers of compact bone
  - Within the cranium, the layer of spongy bone between the compact bone is called the diploë

Figure 6-2b Bone Structure



6-3 Bone (Osseous) Tissue

- Bone (Osseous) Tissue
  - Dense, supportive connective tissue
  - Contains specialized cells
  - Produces solid matrix of calcium salt deposits
  - Around collagen fibers

6-3 Bone (Osseous) Tissue

- Characteristics of Bone Tissue
  - Dense matrix, containing:
    - Deposits of calcium salts
    - Osteocytes (bone cells) within lacunae organized around blood vessels
  - Canaliculi
    - Form pathways for blood vessels
    - Exchange nutrients and wastes

6-3 Bone (Osseous) Tissue

- Characteristics of Bone Tissue
  - Periosteum
    - Covers outer surfaces of bones
    - Consists of outer fibrous and inner cellular layers

6-3 Bone (Osseous) Tissue

- Bone Matrix
  - Minerals
    - Two thirds of bone matrix is calcium phosphate,

      Ca 
      - Reacts with calcium hydroxide, Ca(OH) 
      - To form crystals of hydroxyapatite, Ca 
      - Which incorporates other calcium salts and ions

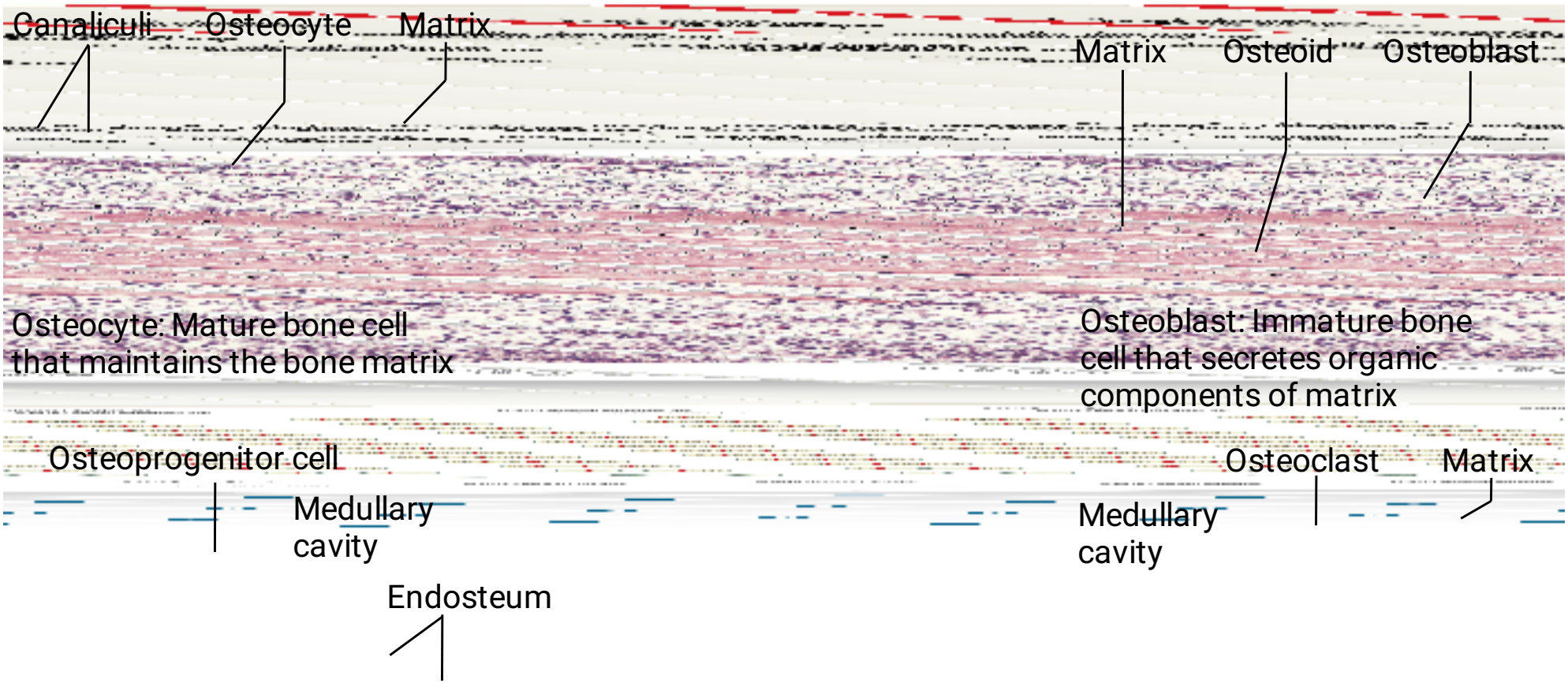
6-3 Bone (Osseous) Tissue

- Bone Matrix
  - Matrix Proteins
    - One third of bone matrix is protein fibers (collagen)

6-3 Bone (Osseous) Tissue

- Bone Cells
  - Make up only 2% of bone mass
  - Bone contains four types of cells
    1. Osteocytes
    2. Osteoblasts
    3. Osteoprogenitor cells
    4. Osteoclasts

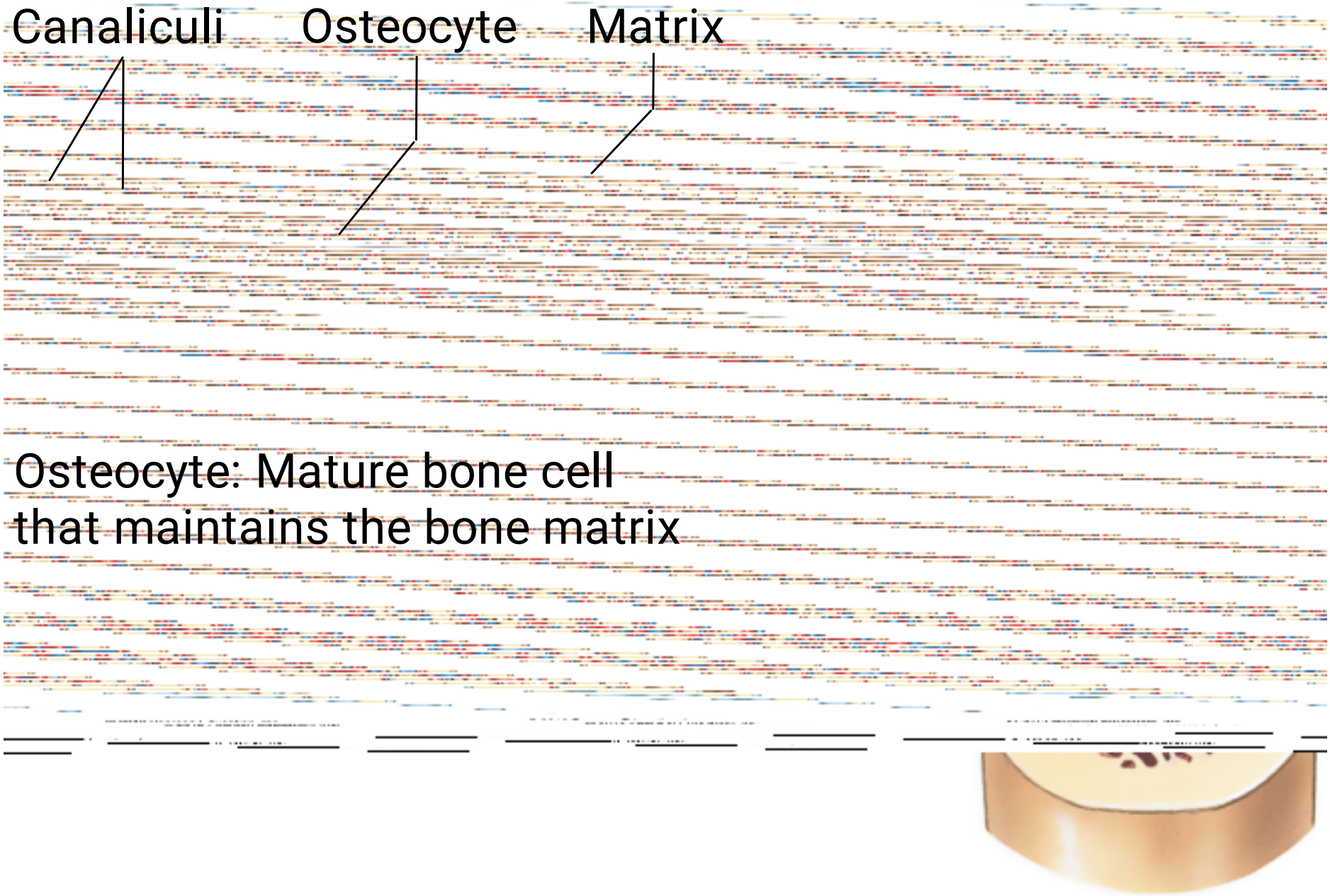
Figure 6-3 Types of Bone Cells



6-3 Bone (Osseous) Tissue

- Osteocytes
  - Mature bone cells that maintain the bone matrix
  - Live in lacunae
  - Are between layers (lamellae) of matrix
  - Connect by cytoplasmic extensions through canaliculi in lamellae
  - Do not divide
  - Two major functions of osteocytes
    1. To maintain protein and mineral content of matrix
    2. To help repair damaged bone

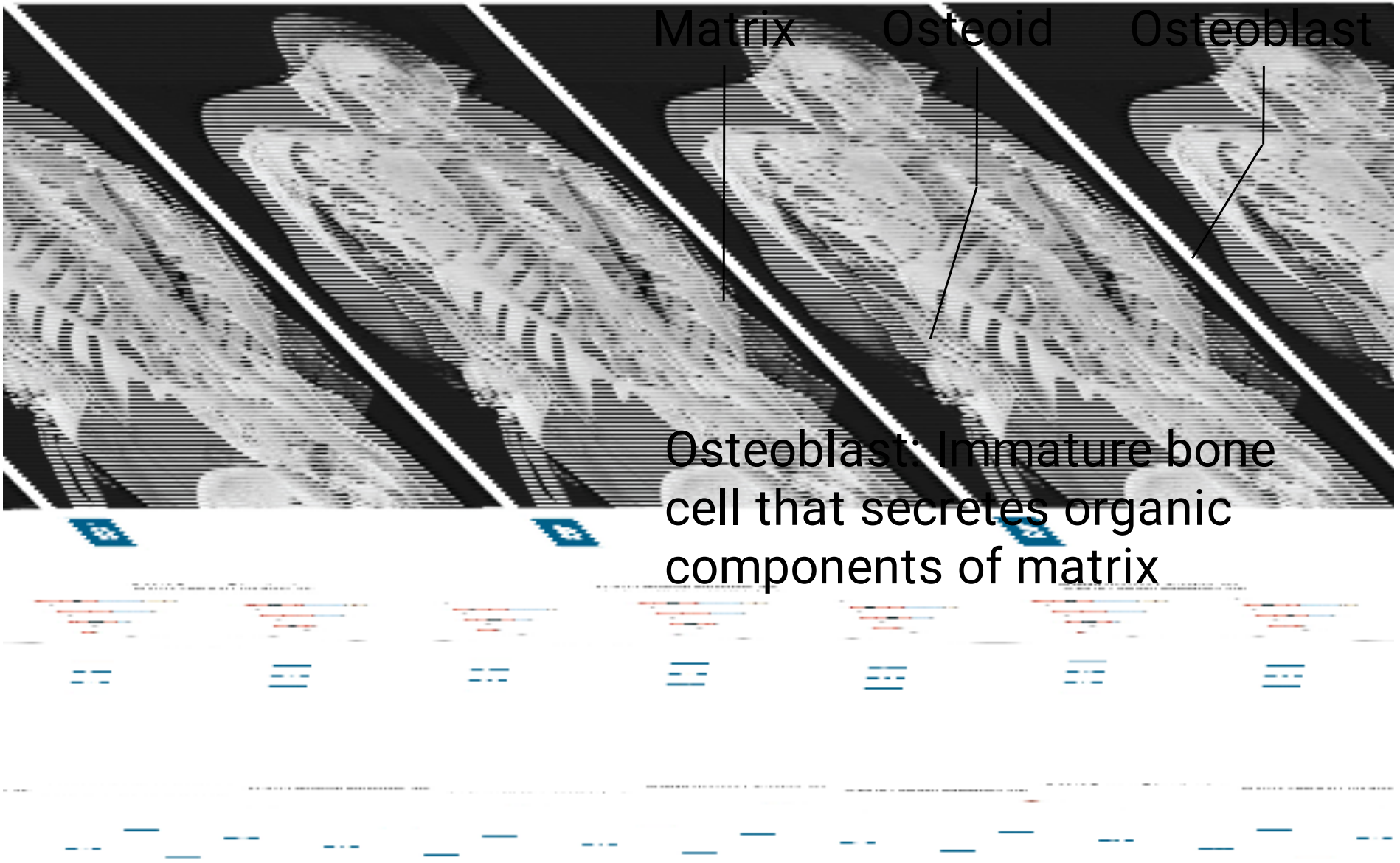
Figure 6-3 Types of Bone Cells



6-3 Bone (Osseous) Tissue

- Osteoblasts
  - Immature bone cells that secrete matrix compounds (osteogenesis)
  - Osteoid — matrix produced by osteoblasts, but not yet calcified to form bone
  - Osteoblasts surrounded by bone become osteocytes

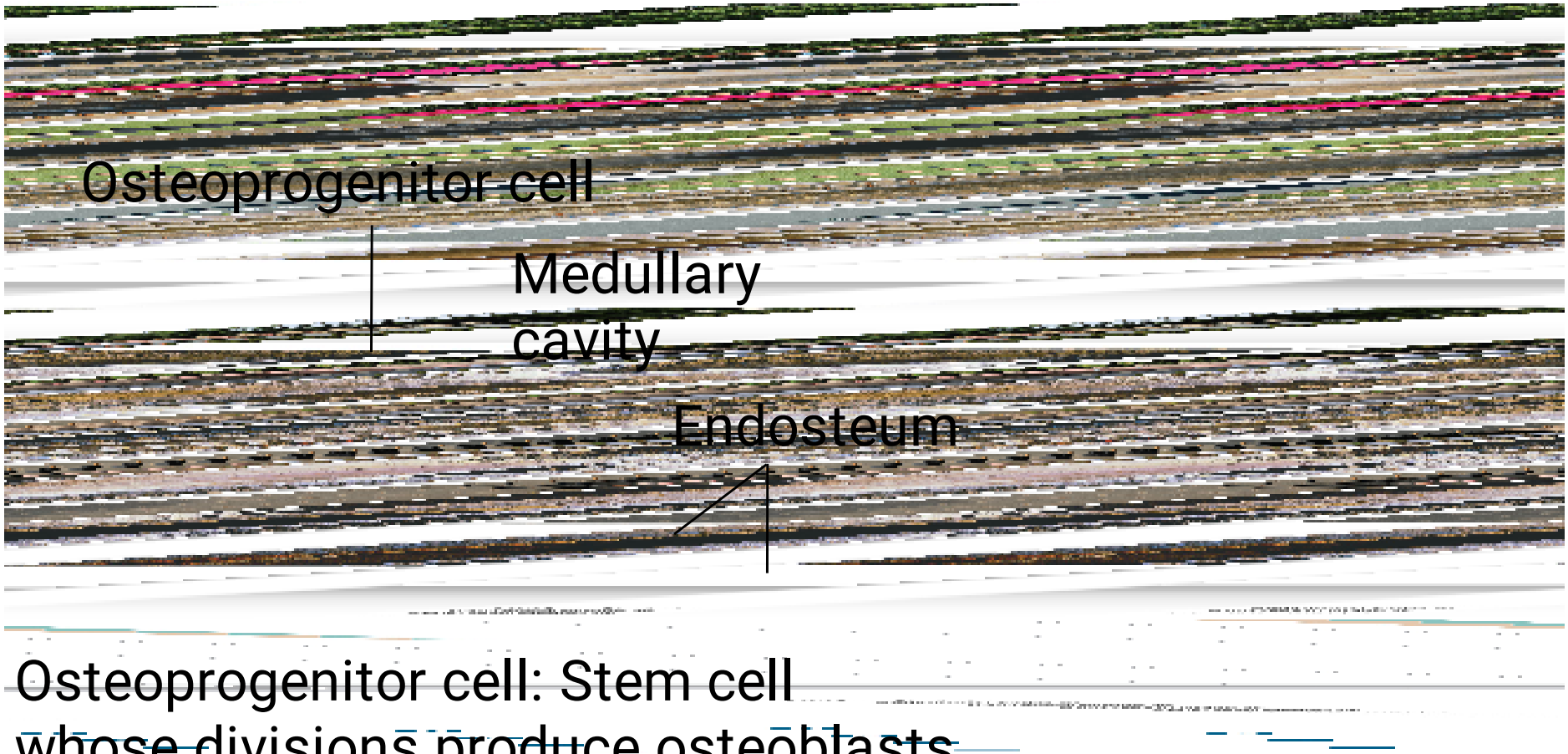
Figure 6-3 Types of Bone Cells



6-3 Bone (Osseous) Tissue

- Osteoprogenitor Cells
  - Mesenchymal stem cells that divide to produce osteoblasts
  - Located in endosteum, the inner cellular layer of periosteum
  - Assist in fracture repair

Figure 6-3 Types of Bone Cells

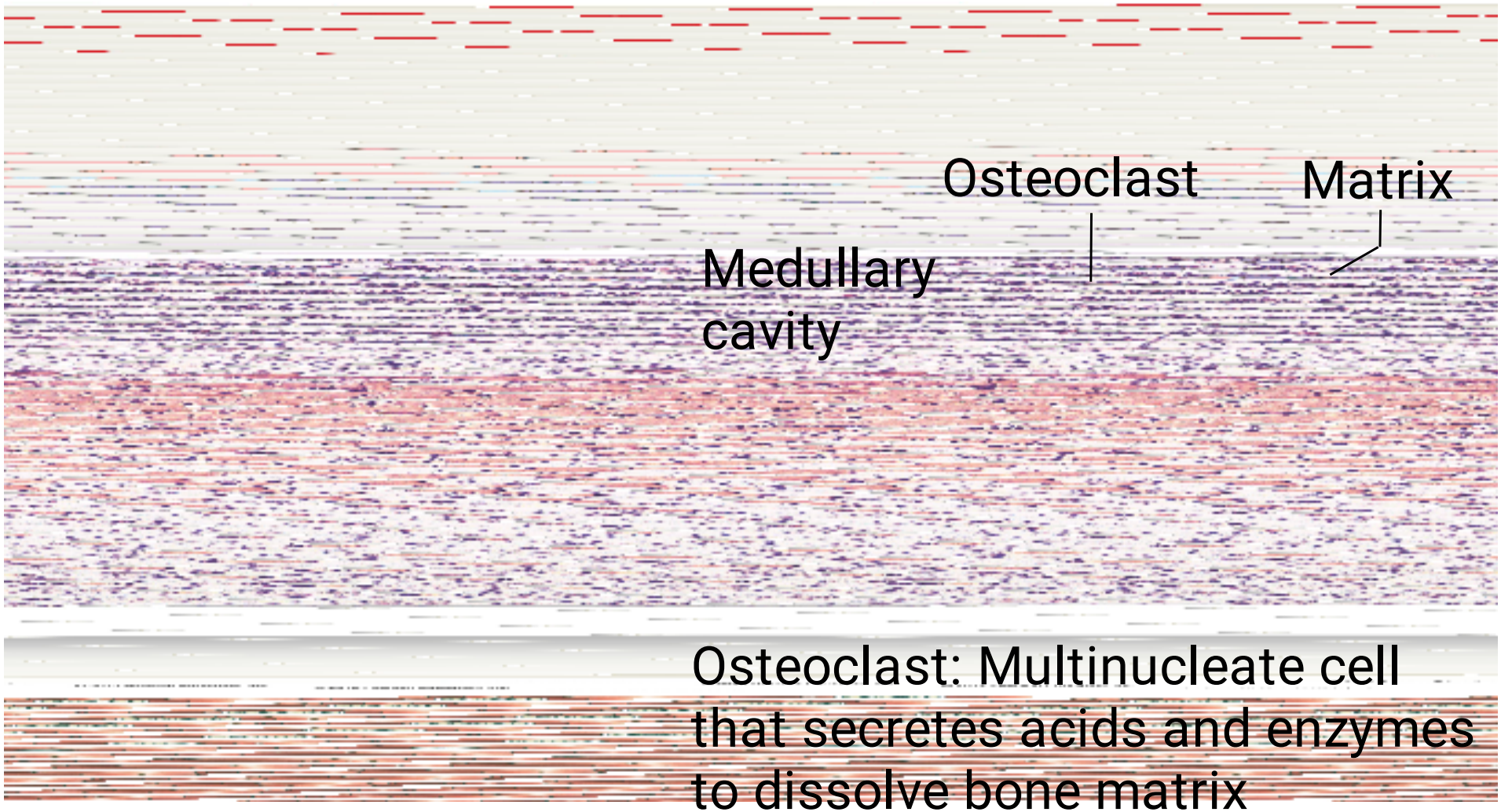


Osteoprogenitor cell: Stem cell whose divisions produce osteoblasts

6-3 Bone (Osseous) Tissue

- Osteoclasts
  - Secrete acids and protein-digesting enzymes
  - Giant, multinucleate cells
  - Dissolve bone matrix and release stored minerals (osteolysis)
  - Derived from stem cells that produce macrophages

Figure 6-3 Types of Bone Cells



6-3 Bone (Osseous) Tissue

- Homeostasis
  - Bone building (by osteoblasts) and bone recycling (by osteoclasts) must balance
    - More breakdown than building, bones become weak
    - Exercise, particularly weight-bearing exercise, causes osteoblasts to build bone

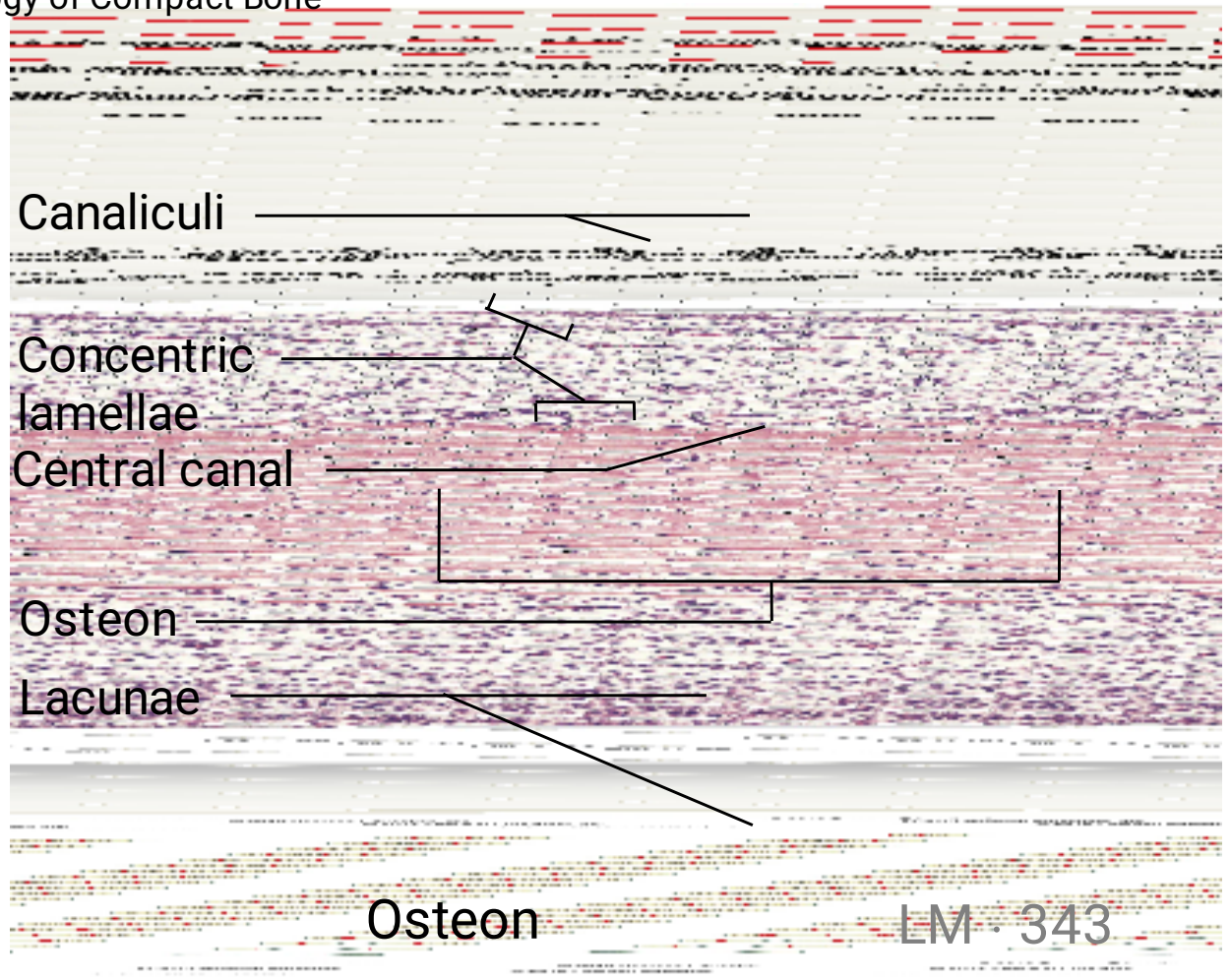
6-4 Compact Bone and Spongy Bone

- The Structure of Compact Bone
  - Osteon is the basic unit
    - Osteocytes are arranged in concentric lamellae
    - Around a central canal containing blood vessels
    - Perforating canals
      - Perpendicular to the central canal
      - Carry blood vessels into bone and marrow

6-4 Compact Bone and Spongy Bone

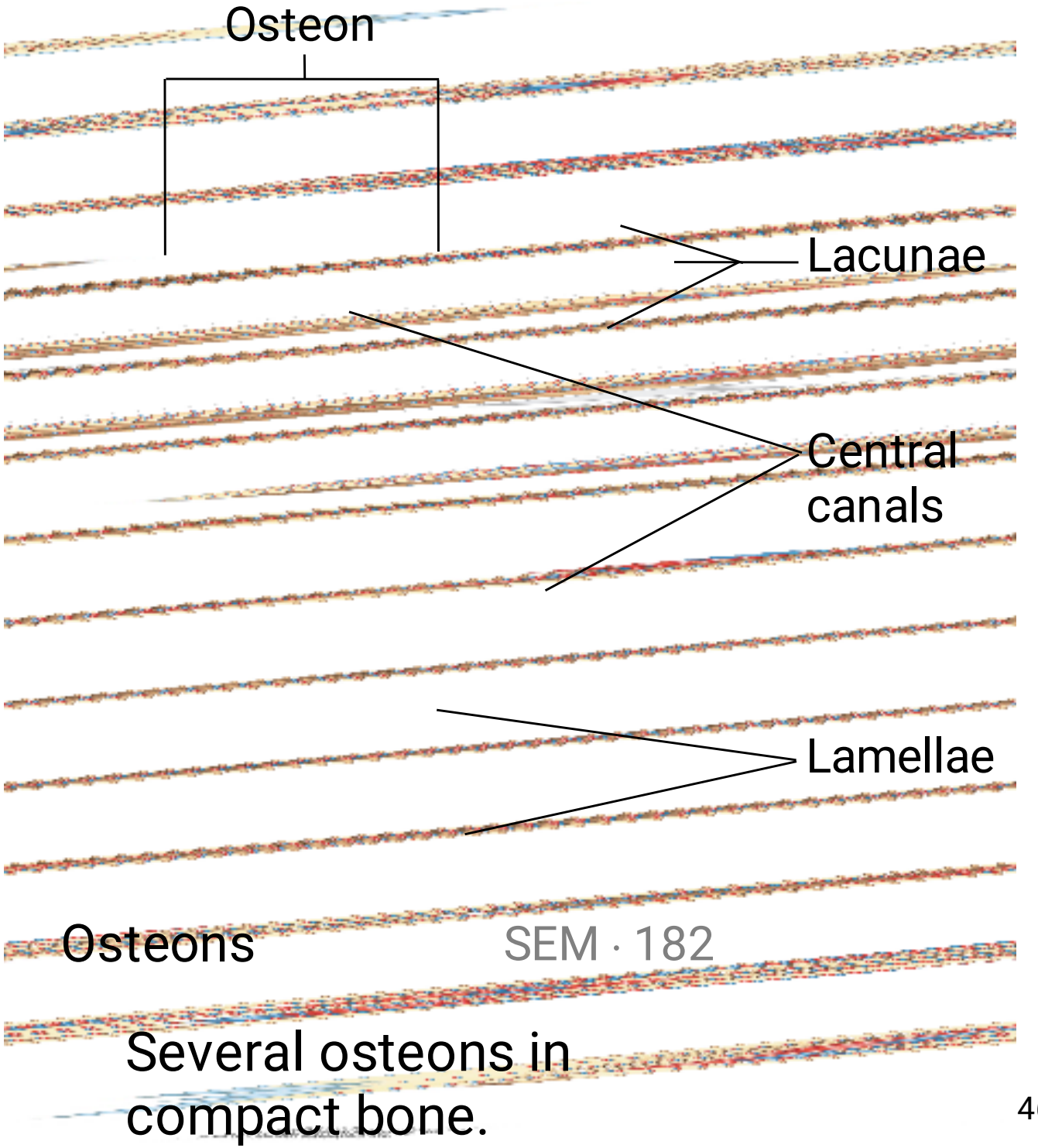
- The Structure of Compact Bone
  - Circumferential Lamellae
    - Lamellae wrapped around the long bone
    - Bind osteons together

Figure 6-4a The Histology of Compact Bone



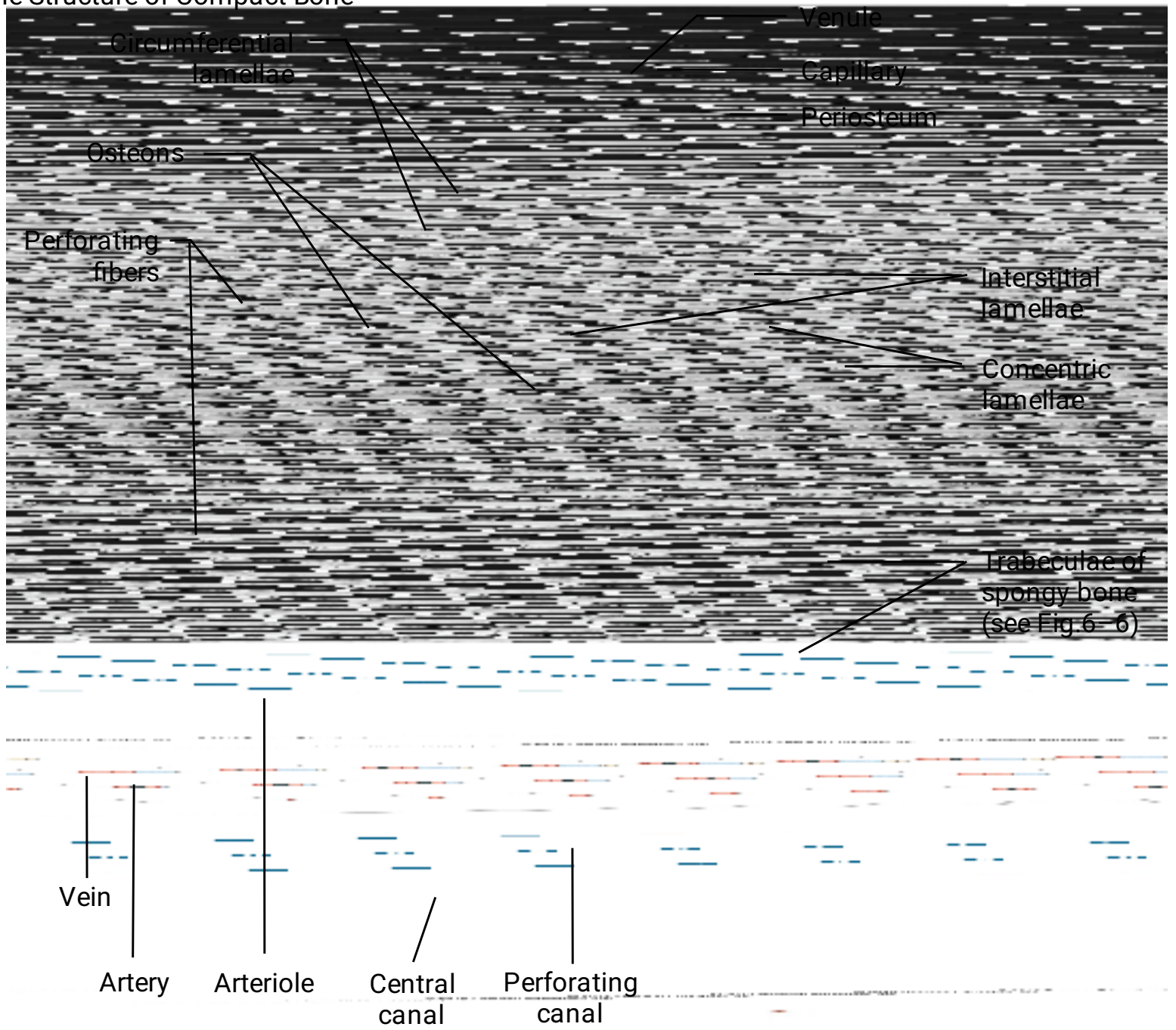
a A thin section through compact bone. By this procedure the intact matrix making up the lamellae appear white, and the central canal, lacunae, and canaliculi appear black due to the presence of bone dust.

Figure 6-4b The Histology of Compact Bone



Several osteons in compact bone.

Figure 6-5a The Structure of Compact Bone



a The organization of osteons and lamellae in compact bone

Figure 6-5a The Structure of Compact Bone

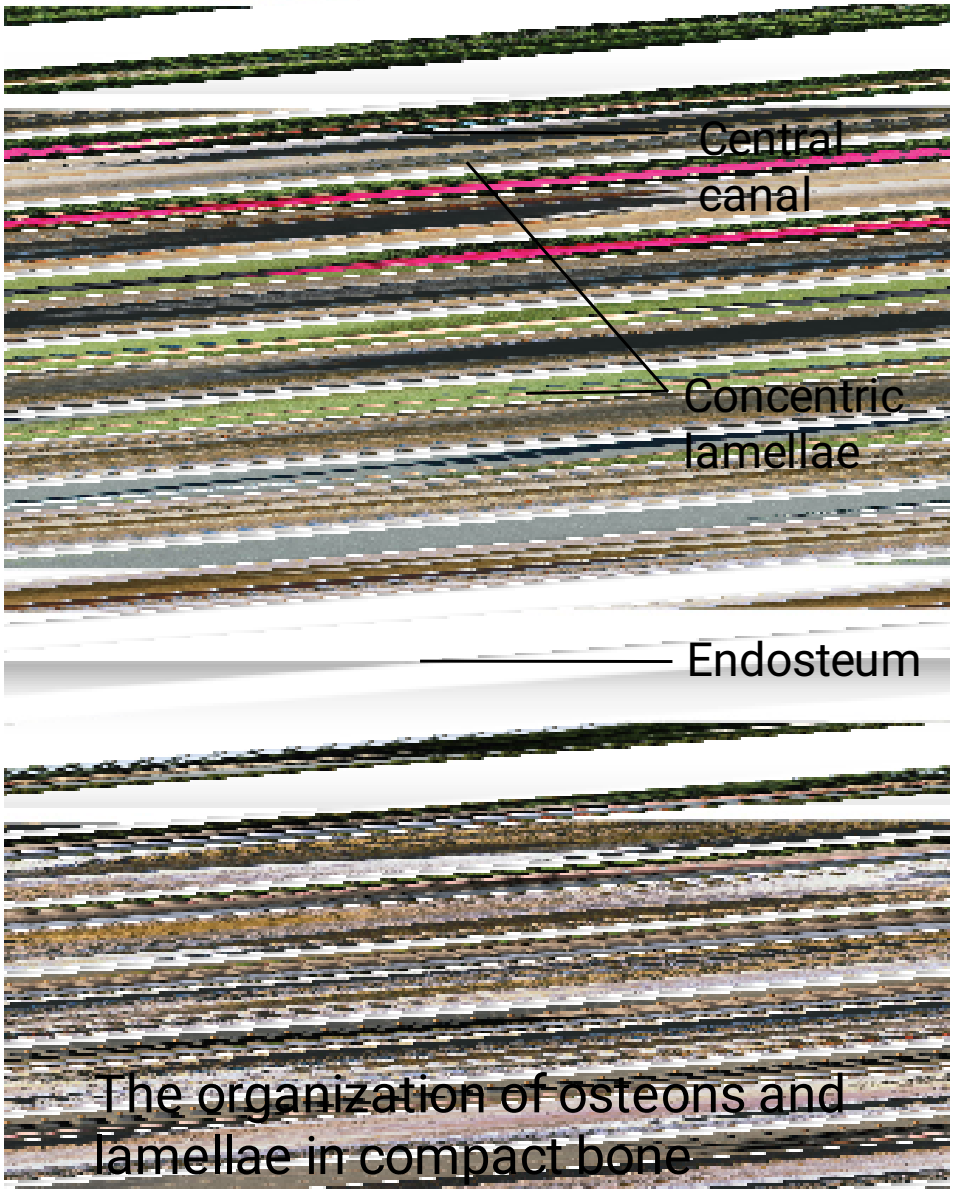
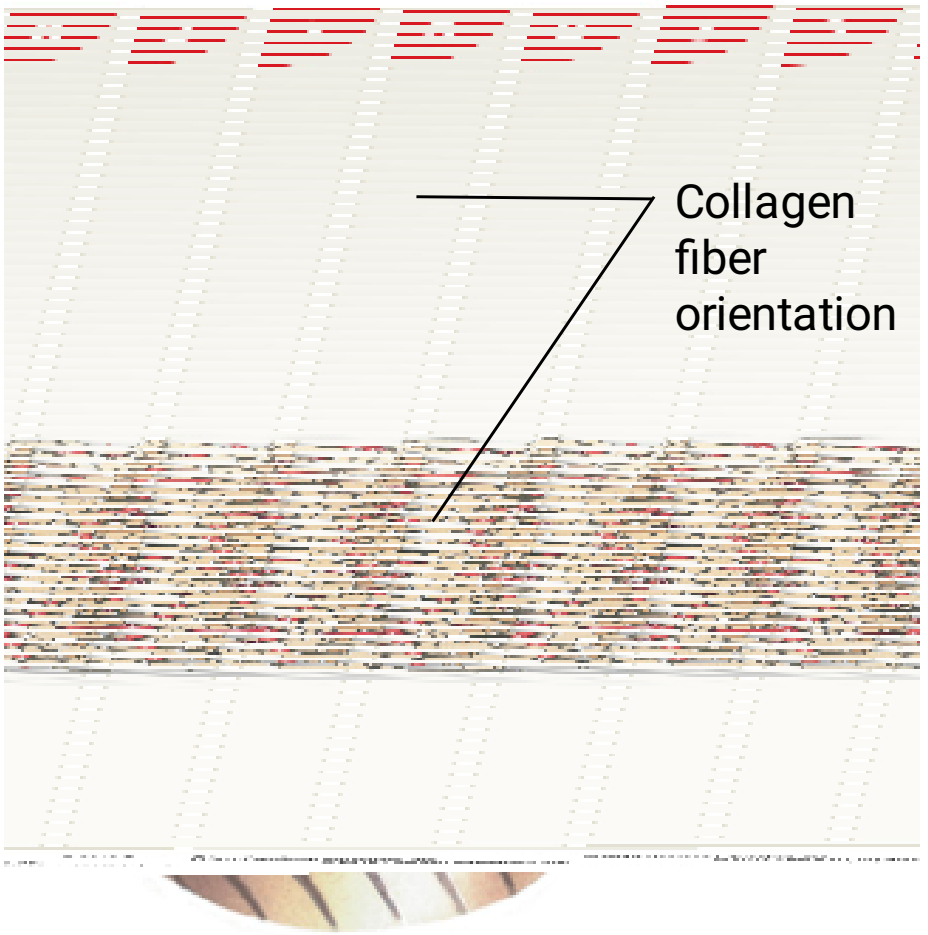


Figure 6-5b The Structure of Compact Bone

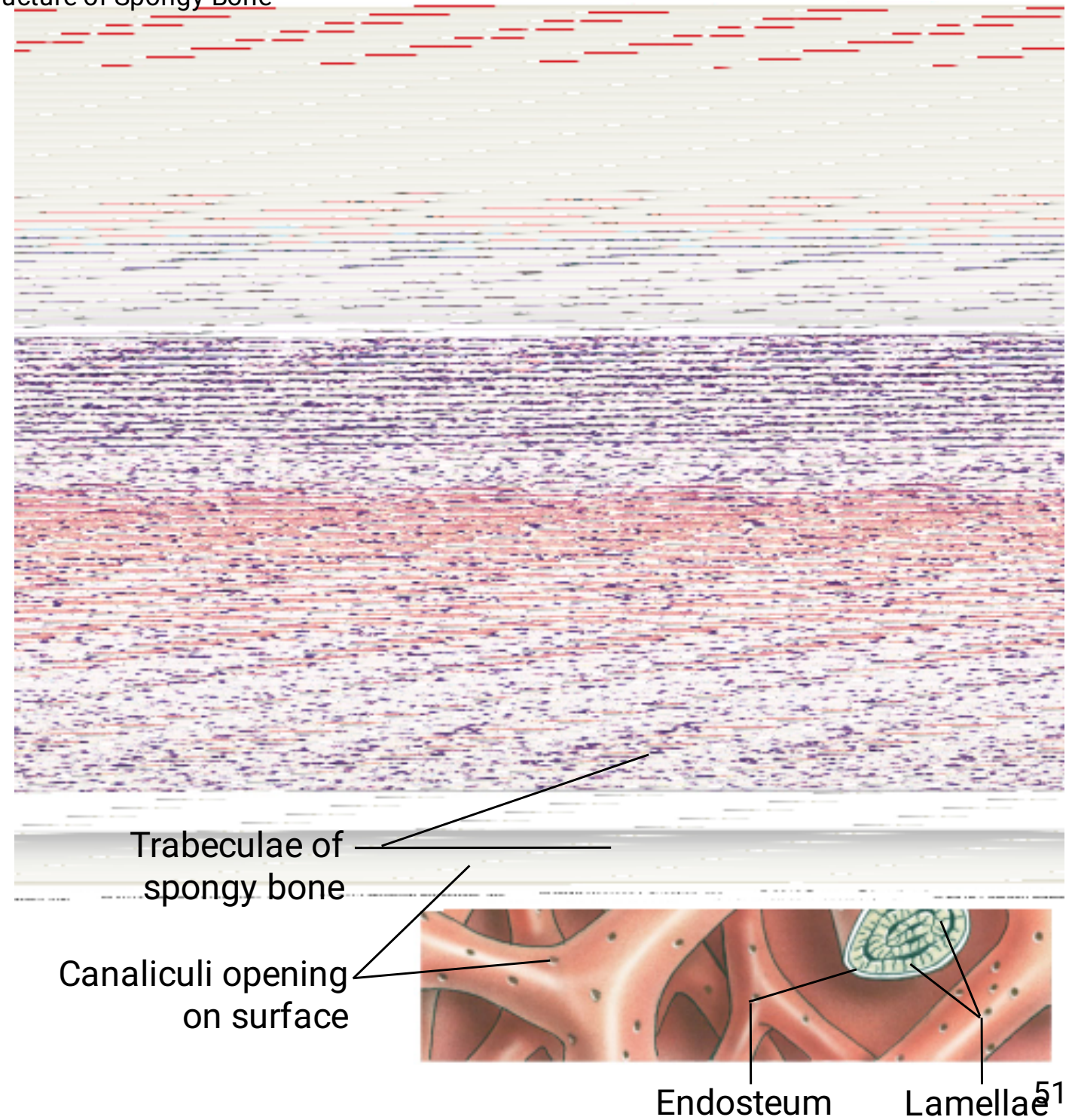


b The orientation of collagen fibers in adjacent lamellae

6-4 Compact Bone and Spongy Bone

- The Structure of Spongy Bone
  - Does not have osteons
  - The matrix forms an open network of trabeculae
  - Trabeculae have no blood vessels
  - The space between trabeculae is filled with red bone marrow
    - Which has blood vessels
    - Forms red blood cells
    - And supplies nutrients to osteocytes
  - Yellow bone marrow
    - In some bones, spongy bone holds yellow bone marrow
    - Is yellow because it stores fat

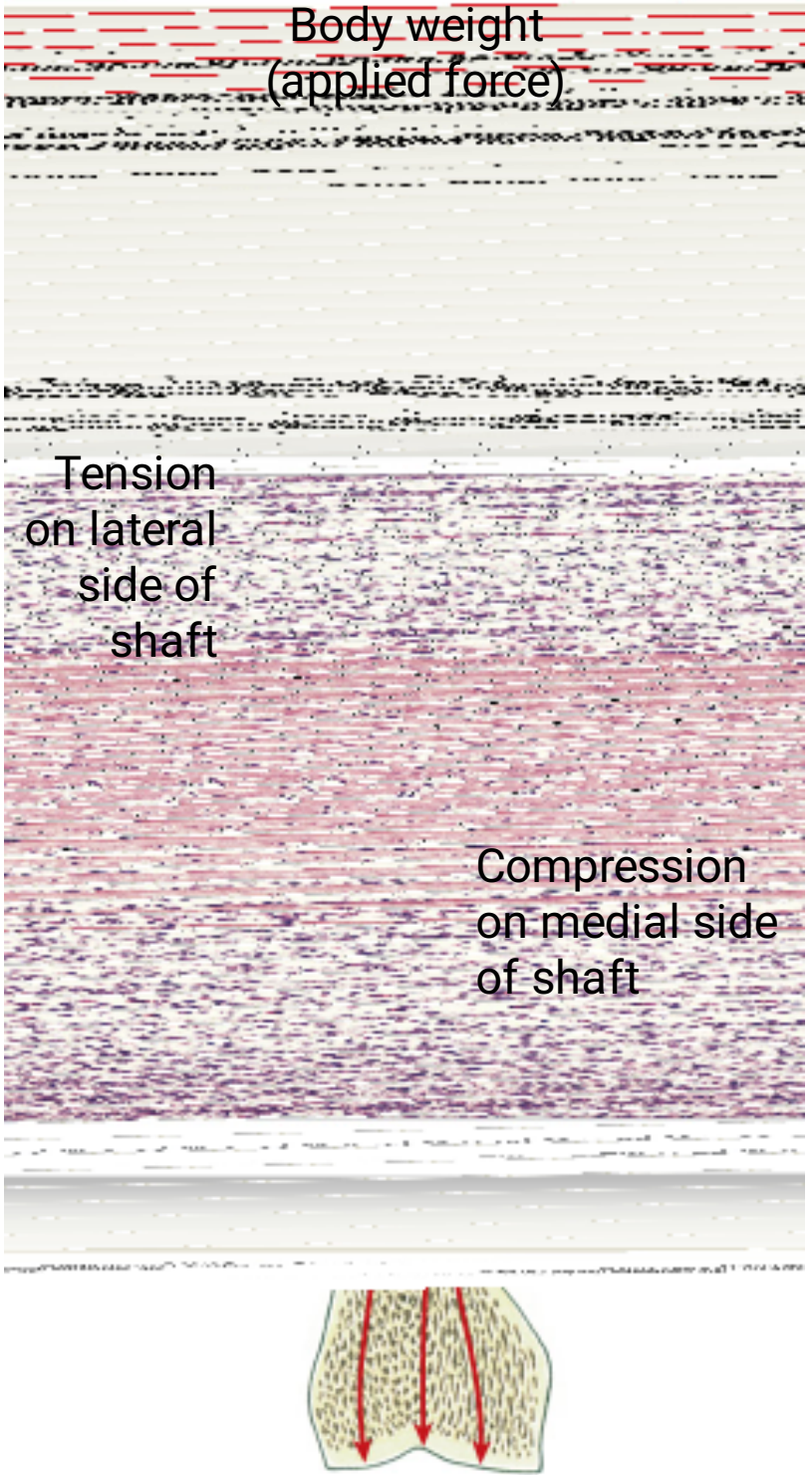
Figure 6-6 The Structure of Spongy Bone



6-4 Compact Bone and Spongy Bone

- Weight-Bearing Bones
  - The femur transfers weight from hip joint to knee joint
    - Causing tension on the lateral side of the shaft
    - And compression on the medial side

Figure 6-7 The Distribution of Forces on a Long Bone



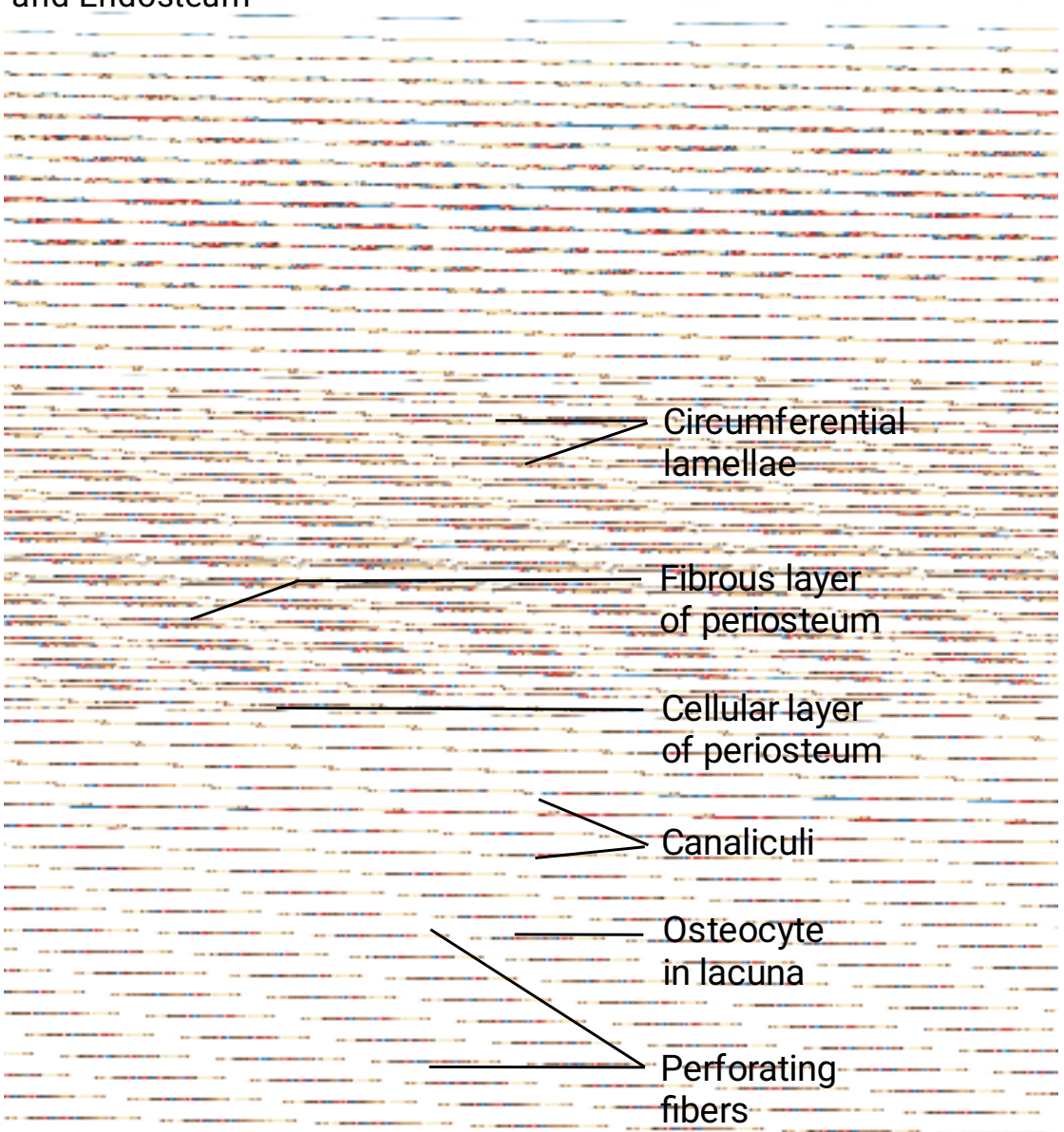
6-4 Compact Bone and Spongy Bone

- Compact Bone is Covered with a Membrane
  - Periosteum on the outside
    - Covers all bones except parts enclosed in joint capsules
    - Made up of an outer, fibrous layer and an inner, cellular layer
    - Perforating fibers: collagen fibers of the periosteum
      - Connect with collagen fibers in bone
      - And with fibers of joint capsules; attach tendons, and ligaments

6-4 Compact Bone and Spongy Bone

- Functions of Periosteum
  1. Isolates bone from surrounding tissues
  2. Provides a route for circulatory and nervous supply
  3. Participates in bone growth and repair

Figure 6-8a The Periosteum and Endosteum

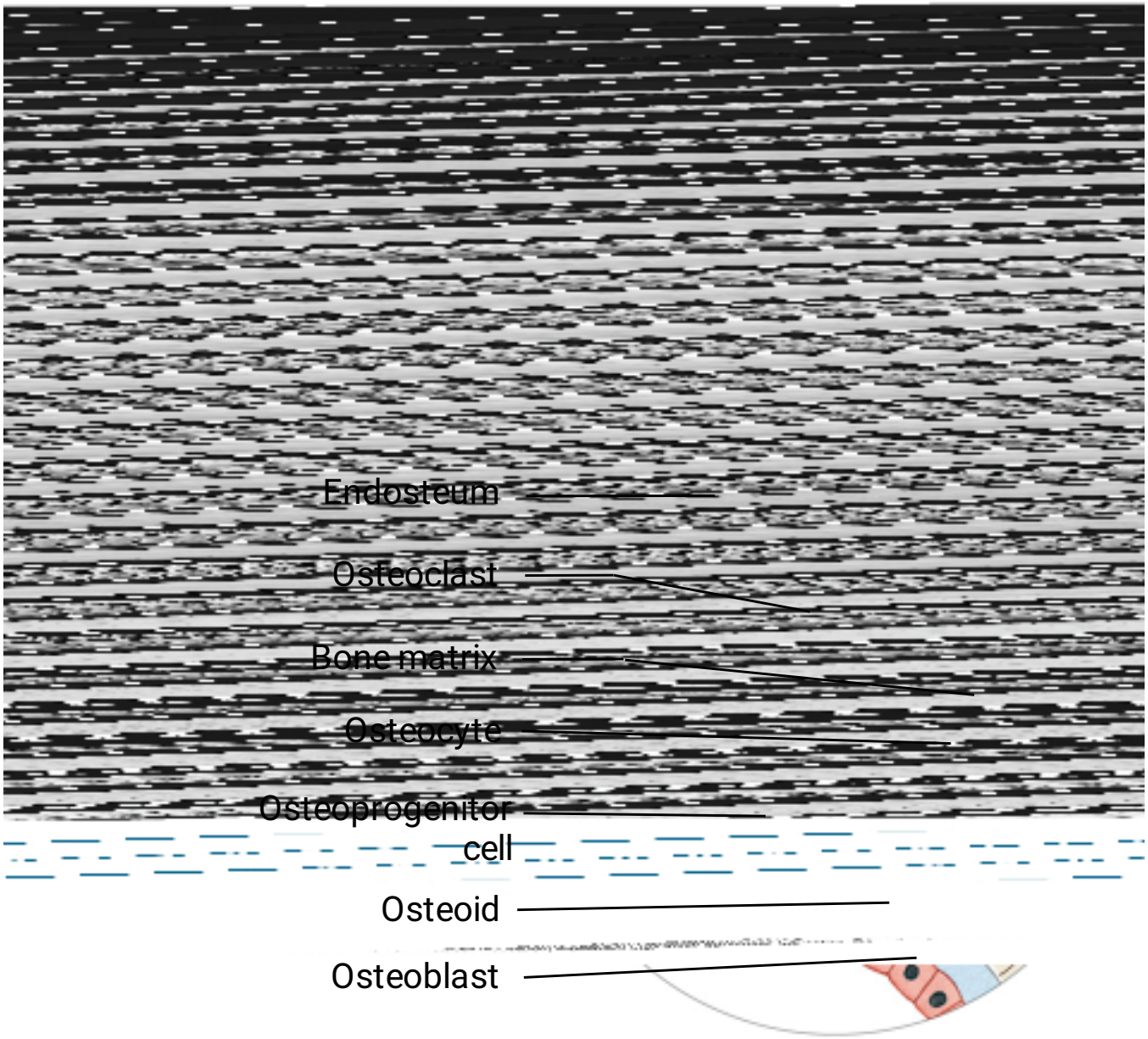


The periosteum contains outer (fibrous) and inner (cellular) layers. Collagen fibers of the periosteum are continuous with those of the bone, adjacent joint capsules, and attached tendons and ligaments.

6-4 Compact Bone and Spongy Bone

- Compact Bone is Covered with a Membrane
  - Endosteum on the inside
    - An incomplete cellular layer:
      - Lines the medullary (marrow) cavity
      - Covers trabeculae of spongy bone
      - Lines central canals
      - Contains osteoblasts, osteoprogenitor cells, and osteoclasts
      - Active in bone growth and repair

Figure 6-8b The Periosteum and Endosteum



b The endosteum is an incomplete cellular layer containing osteoblasts, osteoprogenitor cells, and osteoclasts.

6-5 Bone Formation and Growth

- Bone Development
  - Human bones grow until about age 25
  - Osteogenesis
    - Bone formation
  - Ossification
    - The process of replacing other tissues with bone

6-5 Bone Formation and Growth

- Bone Development
  - Calcification
    - The process of depositing calcium salts
    - Occurs during bone ossification and in other tissues
  - Ossification
    - Two main forms of ossification
      1. Endochondral ossification
      2. Intramembranous ossification

6-5 Bone Formation and Growth

- Endochondral Ossification
  - Ossifies bones that originate as hyaline cartilage
  - Most bones originate as hyaline cartilage
  - There are six main steps in endochondral ossification

6-5 Bone Formation and Growth

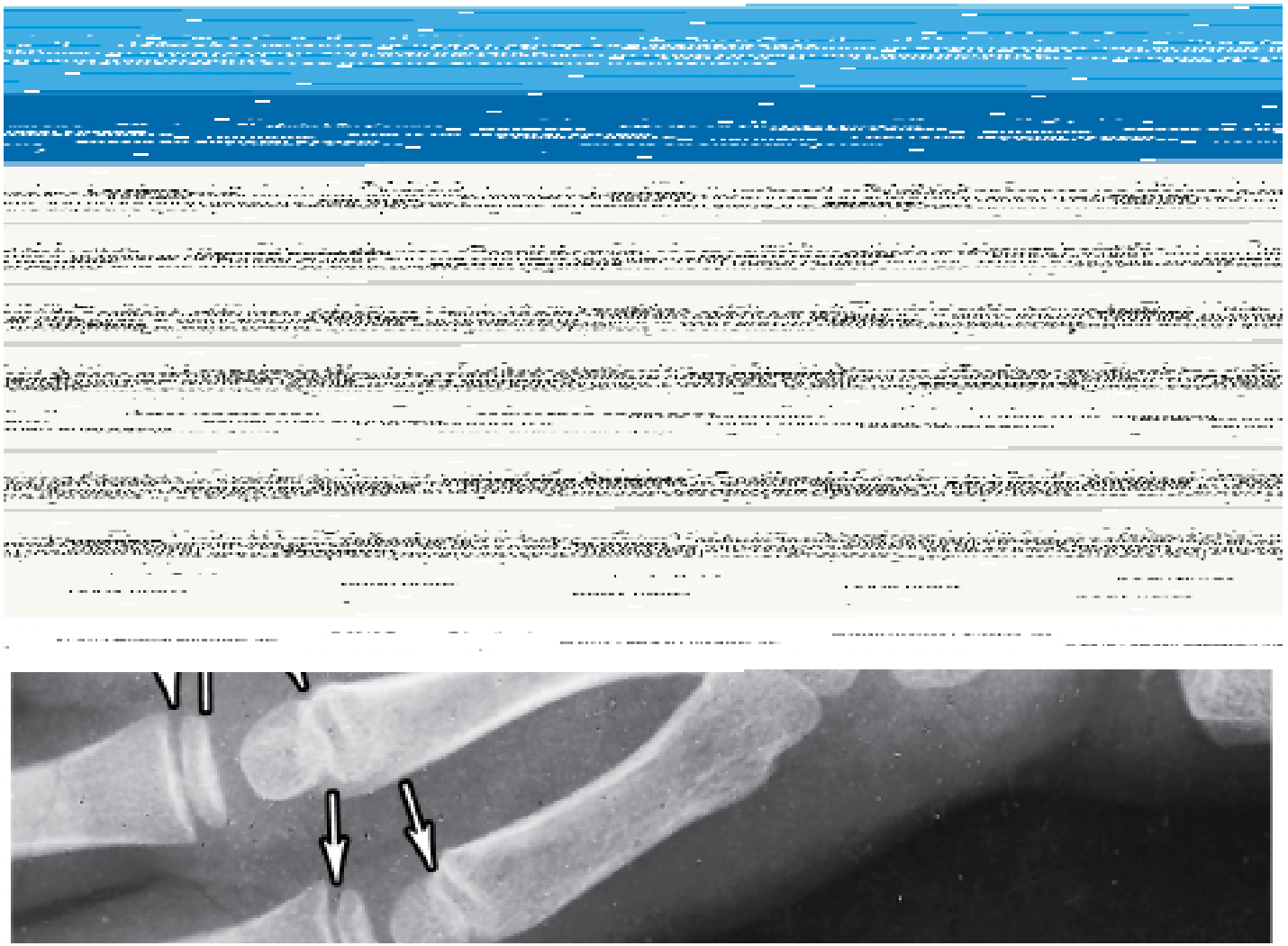
- Appositional Growth
  - Compact bone thickens and strengthens long bone with layers of circumferential lamellae

PLAY ANIMATION Endochondral Ossification

6-5 Bone Formation and Growth

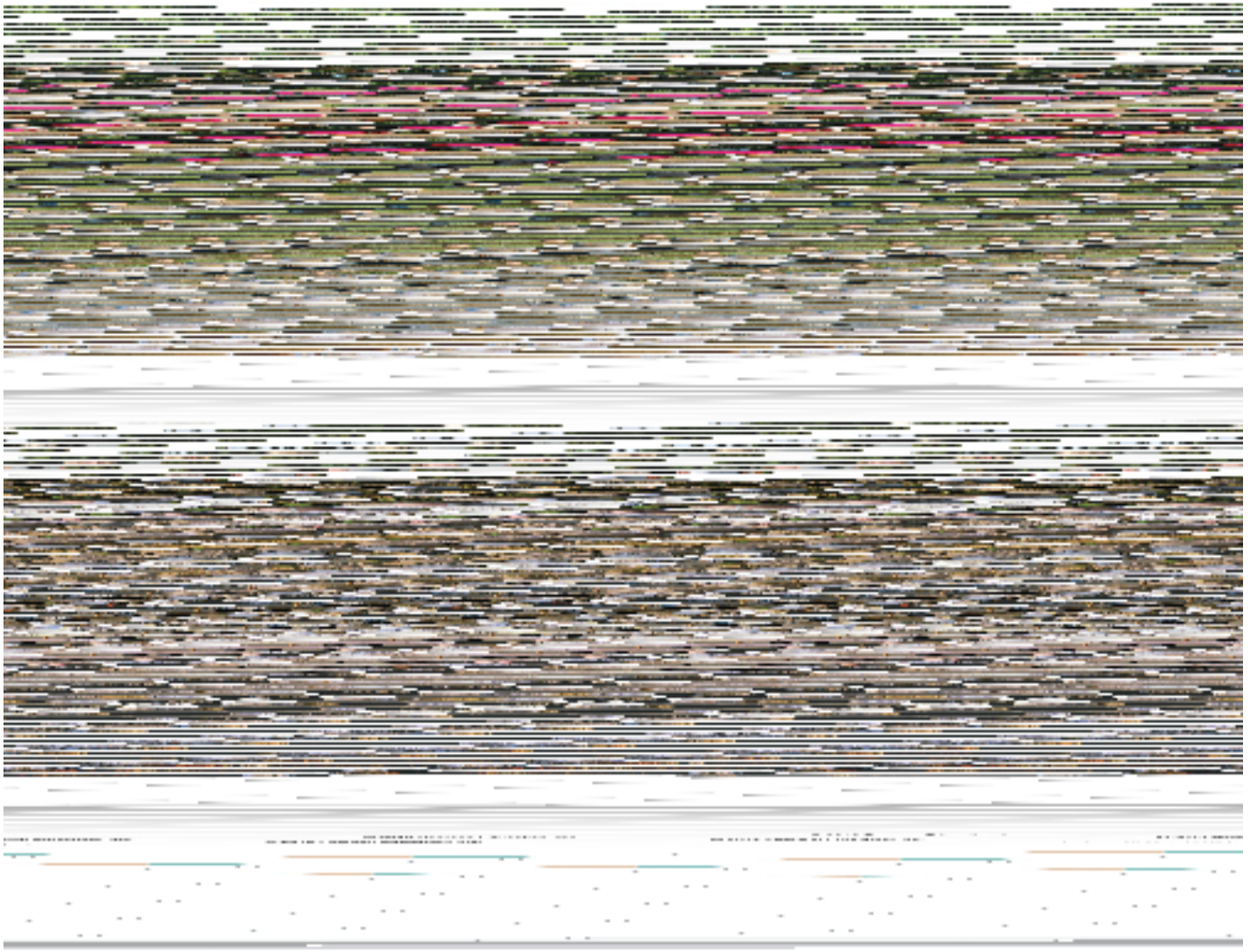
- Epiphyseal Lines
  - When long bone stops growing, after puberty:
    - Epiphyseal cartilage disappears
    - Is visible on X-rays as an epiphyseal line
- Mature Bones
  - As long bone matures:
    - Osteoclasts enlarge medullary (marrow) cavity
    - Osteons form around blood vessels in compact bone

Figure 6-11a Bone Growth at an Epiphyseal Cartilage



a An x-ray of growing epiphyseal cartilages (arrows)

Figure 6-11b Bone Growth at an Epiphyseal Cartilage



- Epiphyseal lines in an adult (arrows)

6-5 Bone Formation and Growth

- Intramembranous Ossification
  - Also called dermal ossification
    - Because it occurs in the dermis
    - Produces dermal bones such as mandible (lower jaw) and clavicle (collarbone)
  - There are three main steps in intramembranous ossification

Figure 6-12 Intramembranous Ossification

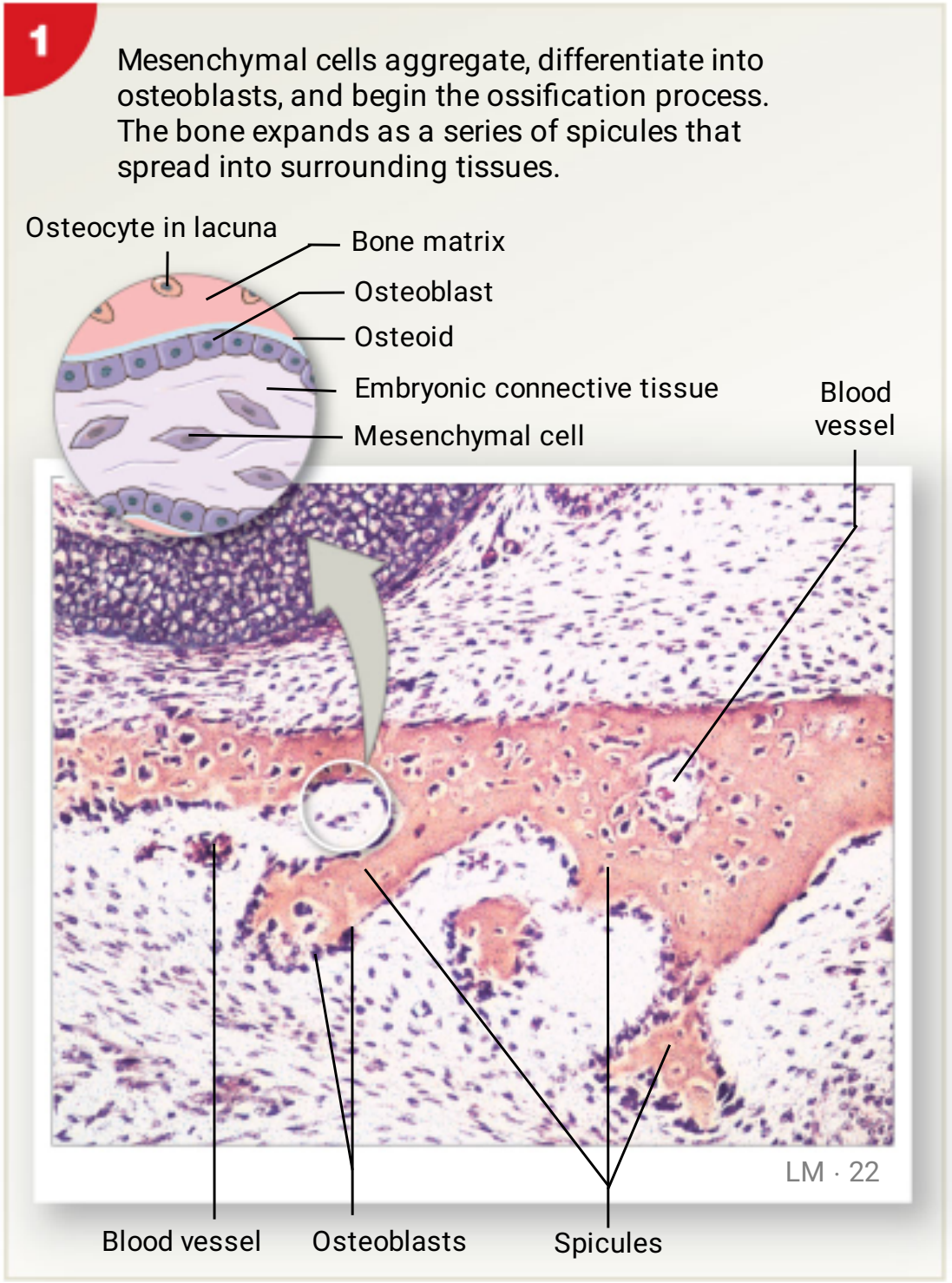


Figure 6-12 Intramembranous Ossification

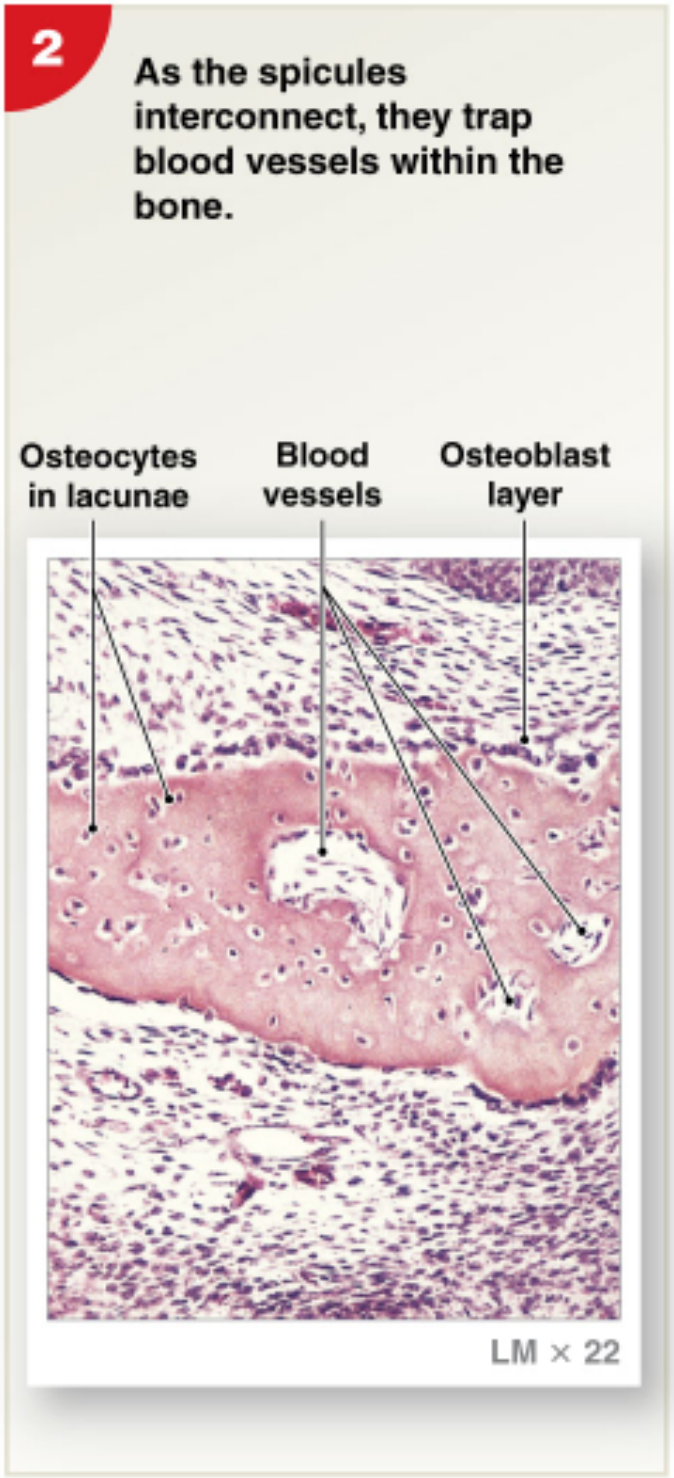
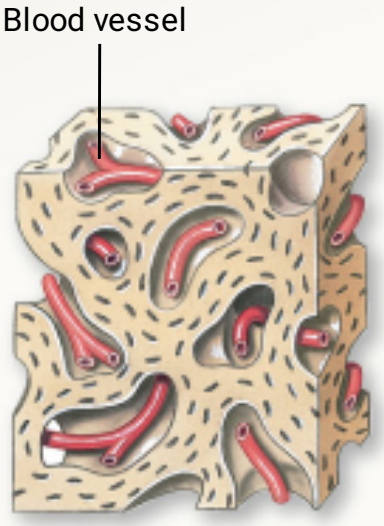


Figure 6-12 Intramembranous Ossification

3

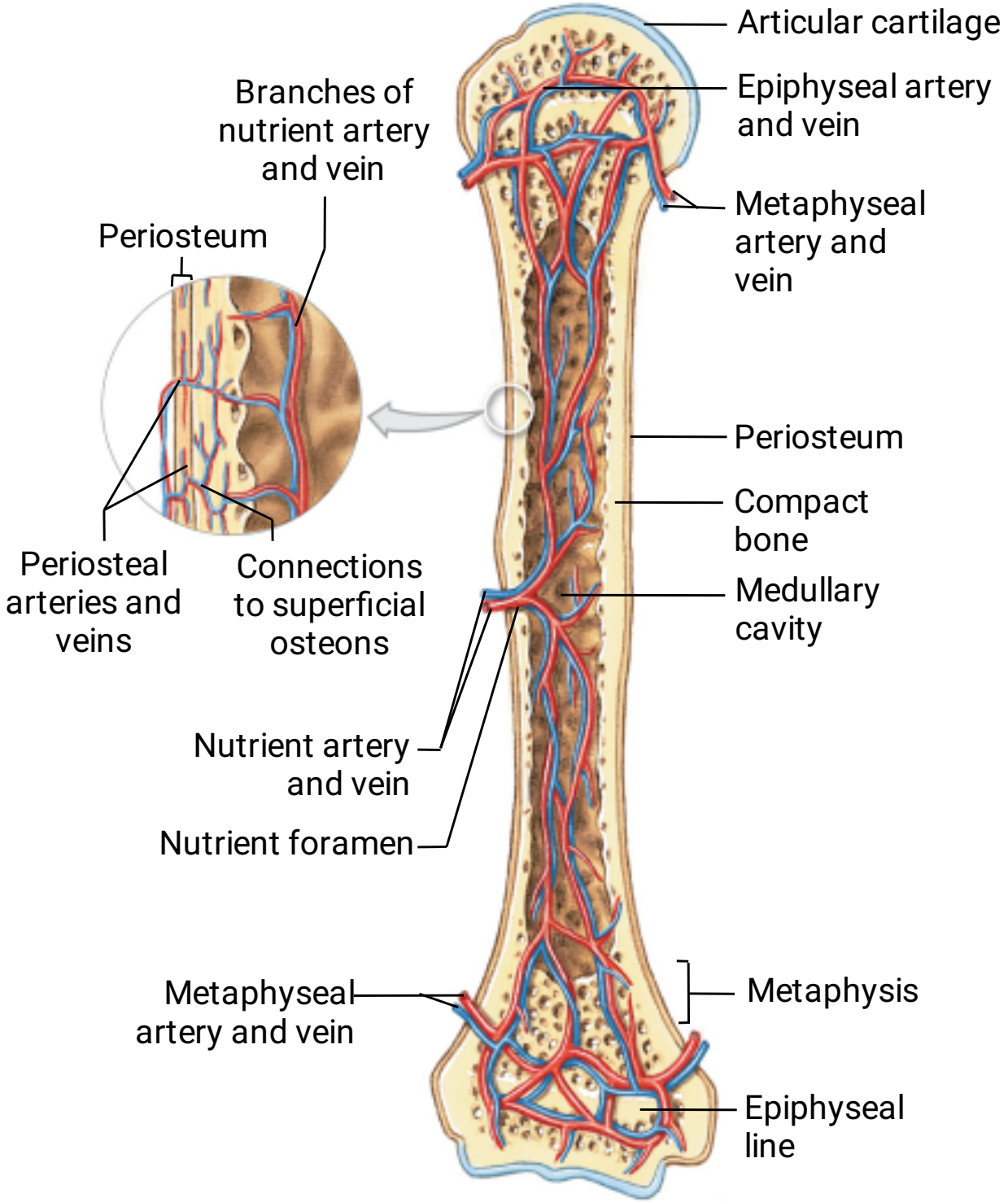
Over time, the bone assumes the structure of spongy bone. Areas of spongy bone may later be removed, creating medullary cavities. Through remodeling, spongy bone formed in this way can be converted to compact bone.



6-5 Bone Formation and Growth

- Blood Supply of Mature Bones
  1. Nutrient Artery and Vein
     - A single pair of large blood vessels
     - Enter the diaphysis through the nutrient foramen
     - Femur has more than one pair
  2. Metaphyseal Vessels
     - Supply the epiphyseal cartilage
     - Where bone growth occurs
  3. Periosteal Vessels
     - Blood to superficial osteons
     - Secondary ossification centers

Figure 6-13 The Blood Supply to a Mature Bone



6-5 Bone Formation and Growth

- Lymph and Nerves
  - The periosteum also contains:
    - Networks of lymphatic vessels
    - Sensory nerves

Figure 6-9 Heterotopic Bone Formation

a An adult male with FOP, posterior view

b The skeleton of a man with advanced FOP

6-6 Bone Remodeling

- Process of Remodeling
  - The adult skeleton:
    - Maintains itself
    - Replaces mineral reserves
    - Recycles and renews bone matrix
    - Involves osteocytes, osteoblasts, and osteoclasts

6-6 Bone Remodeling

- Process of Remodeling
  - Bone continually remodels, recycles, and replaces
  - Turnover rate varies:
    - If deposition is greater than removal, bones get stronger
    - If removal is faster than replacement, bones get weaker

6-7 Exercise, Hormones, and Nutrition

- Effects of Exercise on Bone
  - Mineral recycling allows bones to adapt to stress
  - Heavily stressed bones become thicker and stronger
- Bone Degeneration
  - Bone degenerates quickly
  - Up to one third of bone mass can be lost in a few weeks of inactivity

6-7 Exercise, Hormones, and Nutrition

- Normal Bone Growth and Maintenance Depend on Nutritional and Hormonal Factors
  - A dietary source of calcium and phosphate salts
    - Plus small amounts of magnesium, fluoride, iron, and manganese

6-7 Exercise, Hormones, and Nutrition

- Normal Bone Growth and Maintenance Depend on Nutritional and Hormonal Factors
  - The hormone calcitriol
    - Made in the kidneys
    - Helps absorb calcium and phosphorus from digestive tract
    - Synthesis requires vitamin D

6-7 Exercise, Hormones, and Nutrition

- Normal Bone Growth and Maintenance Depend on Nutritional and Hormonal Factors
  - Vitamin C is required for collagen synthesis, and stimulation of osteoblast differentiation
  - Vitamin A stimulates osteoblast activity
  - Vitamins K and B 

6-7 Exercise, Hormones, and Nutrition

- Normal Bone Growth and Maintenance Depend on Nutritional and Hormonal Factors
  - Growth hormone and thyroxine stimulate bone growth
  - Estrogens and androgens stimulate osteoblasts
  - Calcitonin and parathyroid hormone regulate calcium and phosphate levels

Table 6-2 Hormones Involved in Bone Growth and Maintenance

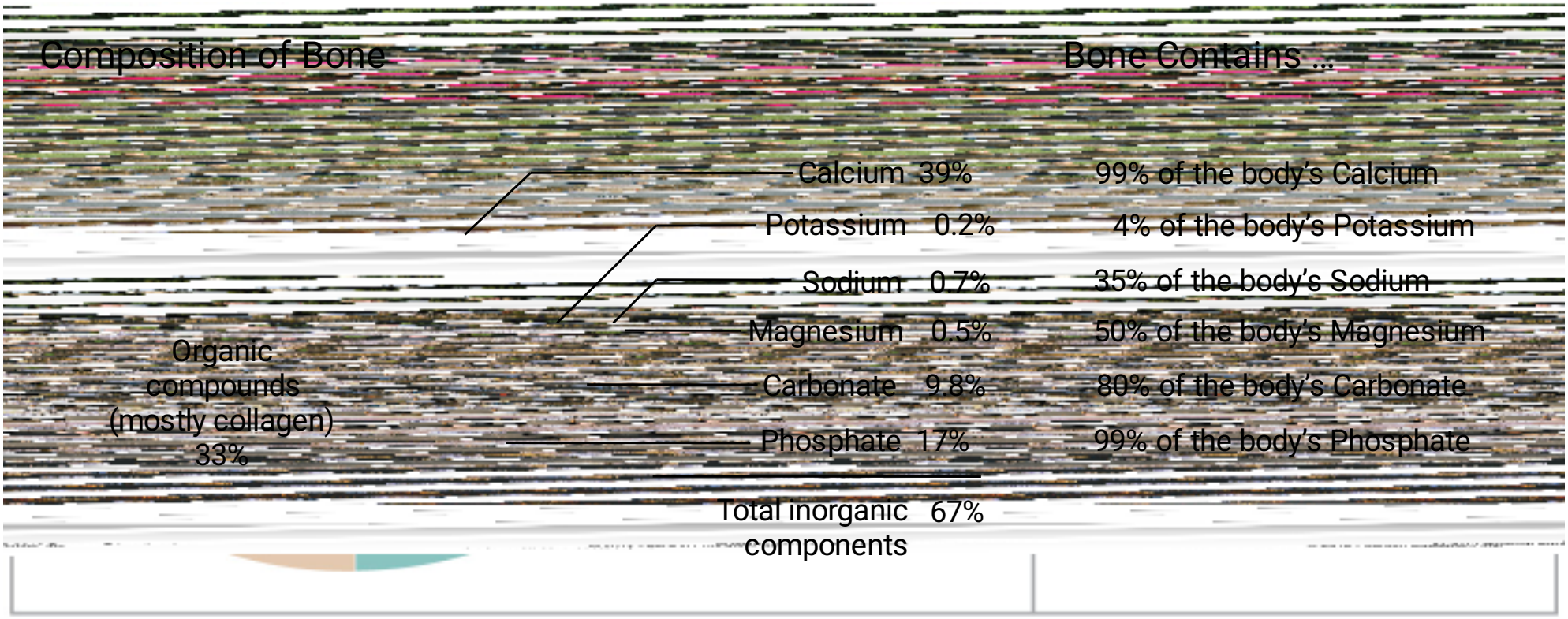
Table 6–2 Hormones Involved in Bone Growth and Maintenance

Hormone	Primary Source	Effects on Skeletal System
Calcitriol	Kidneys	Promotes calcium and phosphate ion absorption along the digestive tract
Growth hormone	Pituitary gland	Stimulates osteoblast activity and the synthesis of bone matrix
Thyroxine	Thyroid gland (follicle cells)	With growth hormone, stimulates osteoblast activity and the synthesis of bone matrix
Sex hormones	Ovaries (estrogens) Testes (androgens)	Stimulate osteoblast activity and the synthesis of bone matrix; estrogens stimulate epiphyseal closure earlier than androgens
Parathyroid hormone	Parathyroid glands	Stimulates osteoclast (and osteoblast) activity; elevates calcium ion concentrations in body fluids
Calcitonin	Thyroid gland (C cells)	Inhibits osteoclast activity; promotes calcium loss by kidneys; reduces calcium ion concentrations in body fluids

6-8 Calcium Homeostasis

- The Skeleton as a Calcium Reserve
  - Bones store calcium and other minerals
  - Calcium is the most abundant mineral in the body
    - Calcium ions are vital to:
      - Membranes
      - Neurons
      - Muscle cells, especially heart cells

Figure 6-15 A Chemical Analysis of Bone



6-8 Calcium Homeostasis

- Calcium Regulation
  - Calcium ions in body fluids
    - Must be closely regulated
  - Homeostasis is maintained
    - By calcitonin and parathyroid hormone (PTH)
    - Which control storage, absorption, and excretion

6-8 Calcium Homeostasis

- Calcitonin and Parathyroid Hormone Control
  - Affect:
    1. Bones
       - Where calcium is stored
    2. Digestive tract
       - Where calcium is absorbed
    3. Kidneys
       - Where calcium is excreted

6-8 Calcium Homeostasis

- Parathyroid Hormone (PTH)
  - Produced by parathyroid glands in neck
  - Increases calcium ion levels by:
    1. Stimulating osteoclasts
    2. Increasing intestinal absorption of calcium
    3. Decreasing calcium excretion at kidneys
- Calcitonin
  - Secreted by C cells (parafollicular cells) in thyroid
  - Decreases calcium ion levels by:
    1. Inhibiting osteoclast activity
    2. Increasing calcium excretion at kidneys

Figure 6-16a Factors That Alter the Concentration of Calcium Ions in Body Fluids

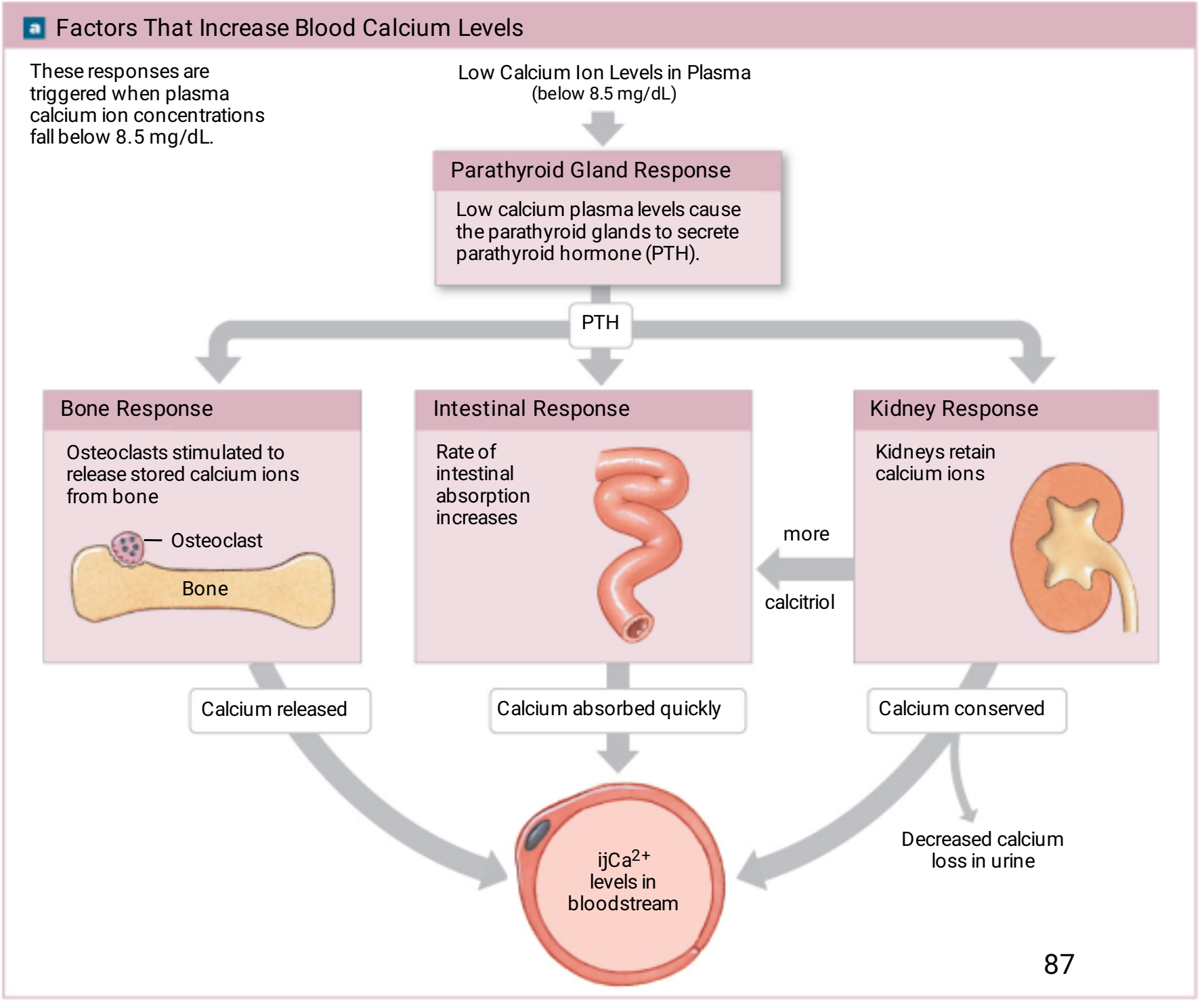
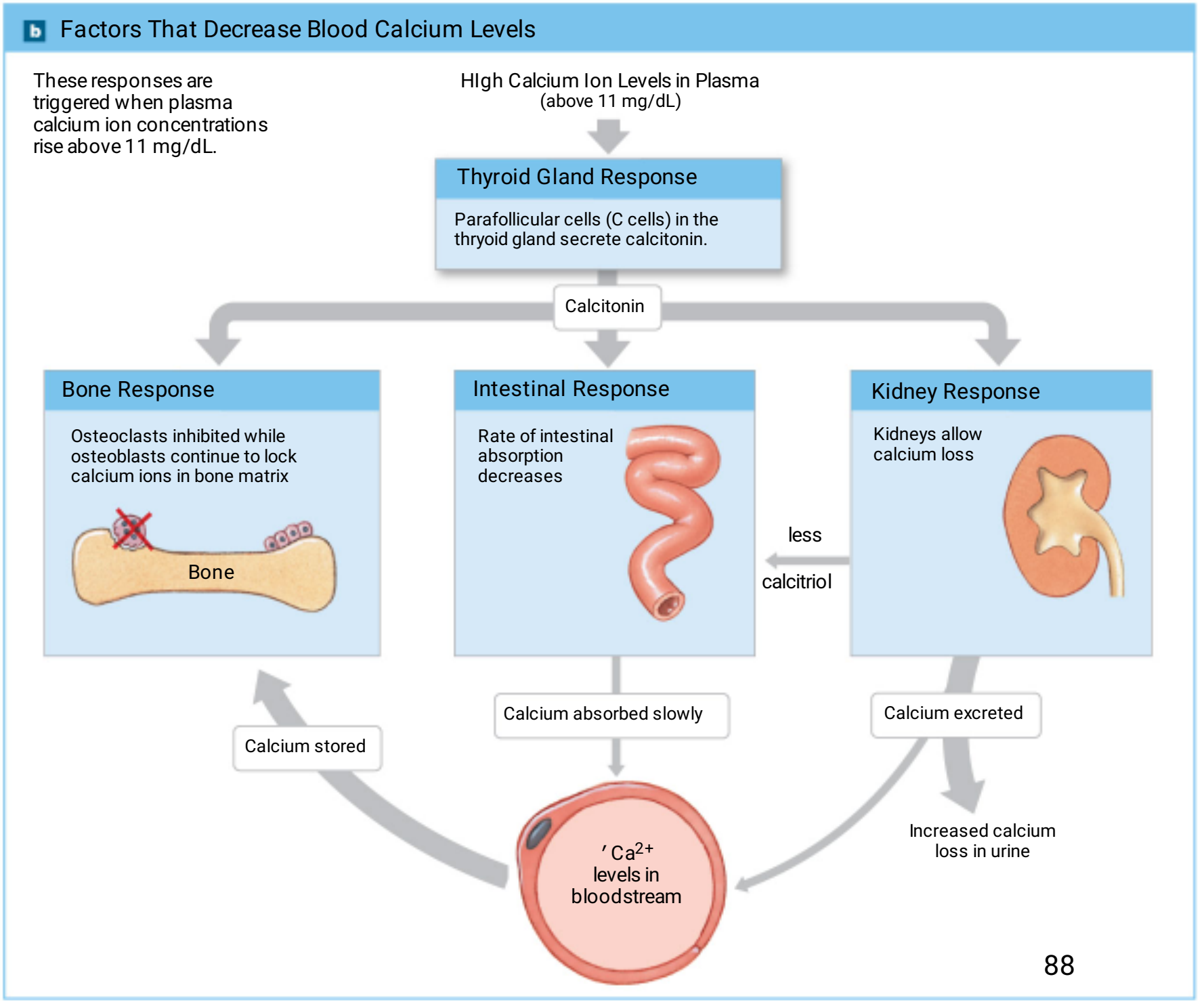


Figure 6-16b Factors That Alter the Concentration of Calcium Ions in Body Fluids



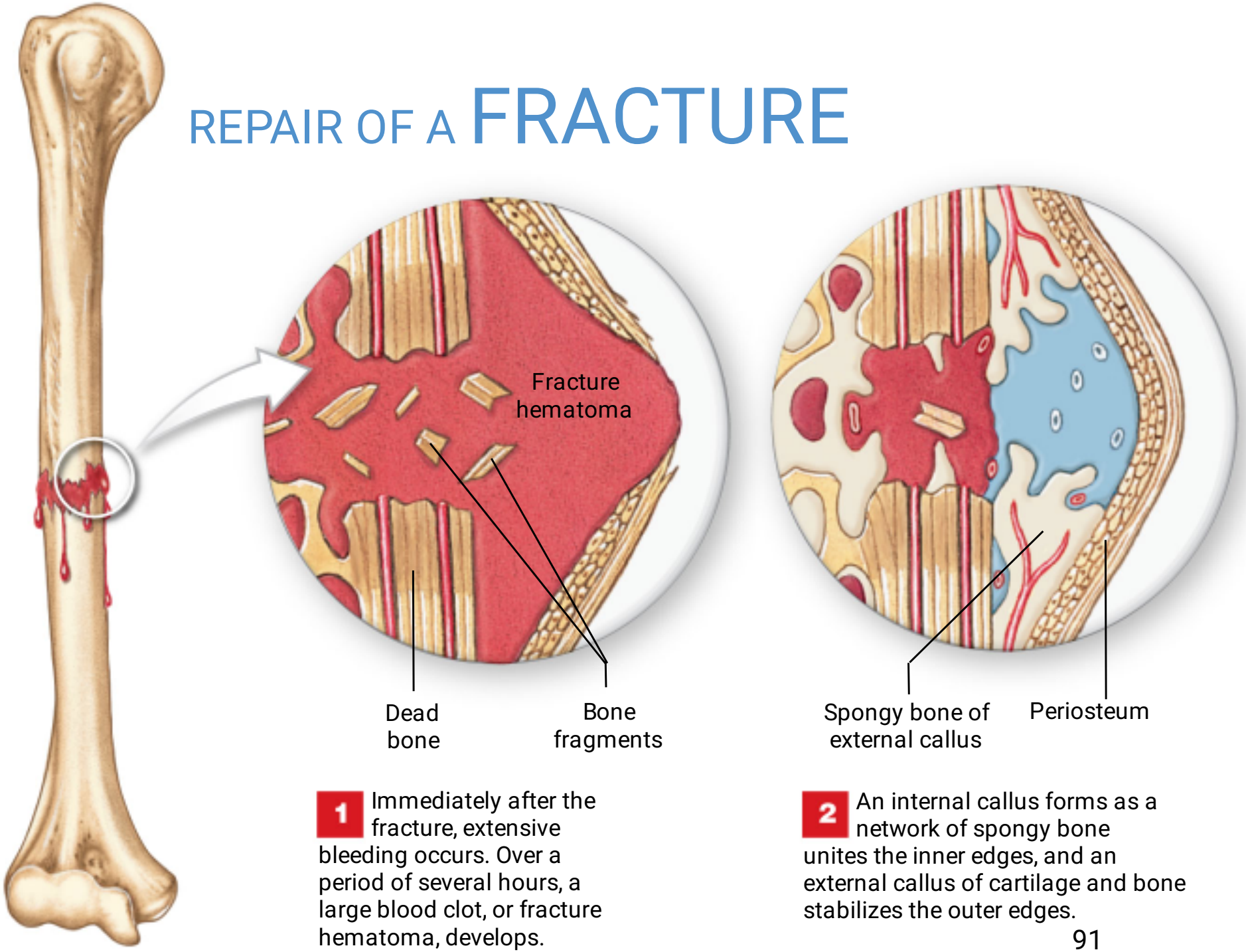
6-9 Fractures

- Fractures
  - Cracks or breaks in bones
  - Caused by physical stress
- Fractures are repaired in four steps
  1. Bleeding
  2. Cells of the endosteum and periosteum
  3. Osteoblasts
  4. Osteoblasts and osteocytes remodel the fracture for up to a year

6-9 Fractures

- Bleeding
  - Produces a clot (fracture hematoma)
  - Establishes a fibrous network
  - Bone cells in the area die
- Cells of the endosteum and periosteum
  - Divide and migrate into fracture zone
  - Calluses stabilize the break
    - External callus of cartilage and bone surrounds break
    - Internal callus develops in medullary cavity

Figure 6-17 Types of Fractures and Steps in Repair

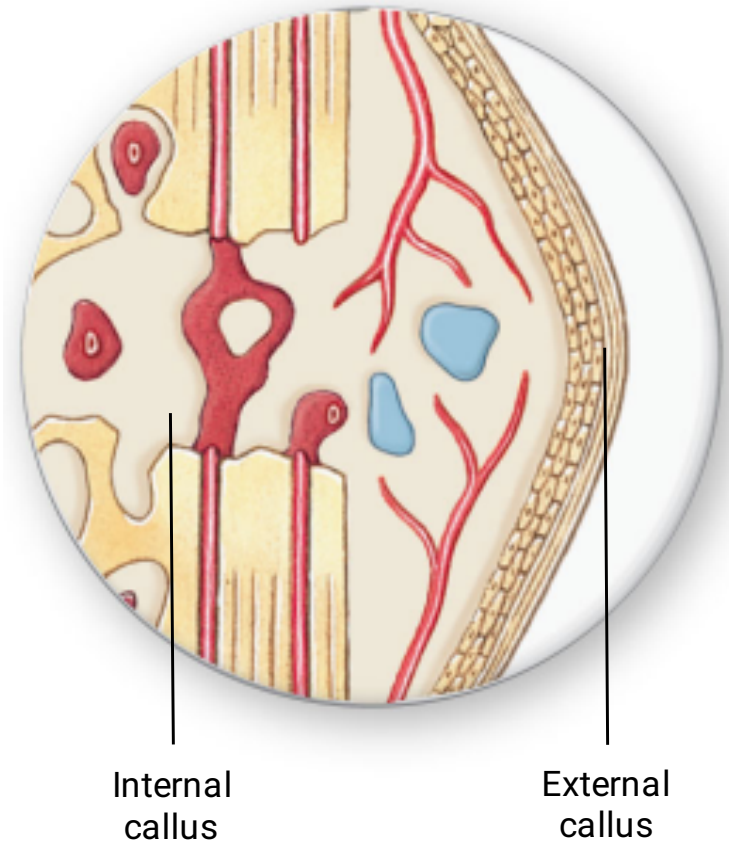


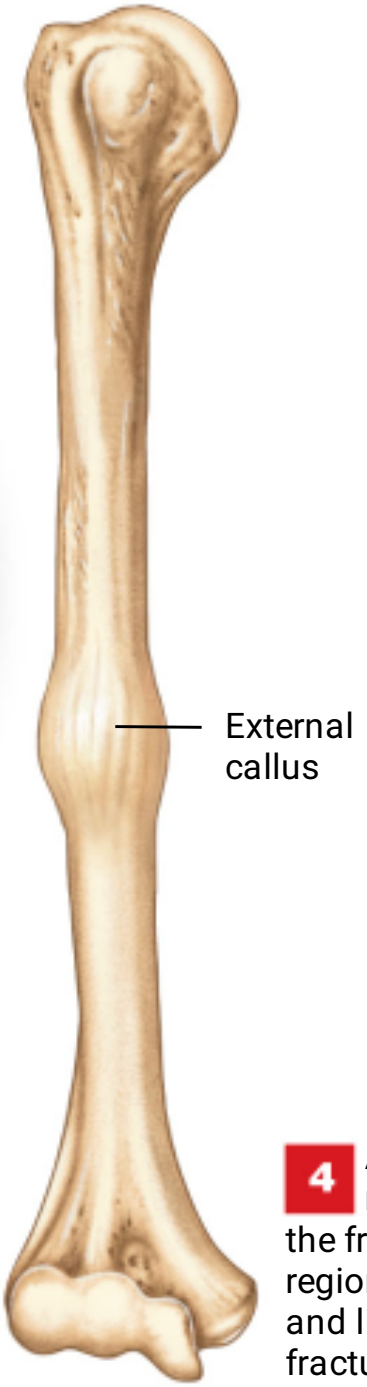
6-9 Fractures

- Osteoblasts
  - Replace central cartilage of external callus
  - With spongy bone

- Osteoblasts and osteocytes remodel the fracture for up to a year
  - Reducing bone calluses

Figure 6-17 Types of Fractures and Steps in Repair





3 The cartilage of the external callus has been replaced by bone, and struts of spongy bone now united the broken ends. Fragments of dead bone and the areas of bone closest to the break have been removed and replaced.

4 A swelling initially marks the location of the fracture. Over time, this region will be remodeled, and little evidence of the fracture will remain.

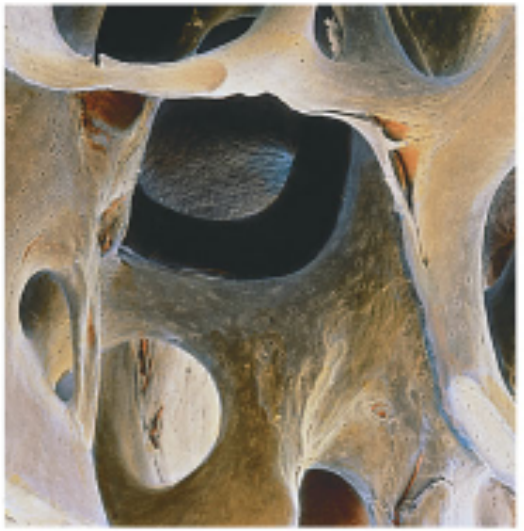
6-10 Effects of Aging on the Skeletal System

- Age-Related Changes
  - Bones become thinner and weaker with age
    - Osteopenia begins between ages 30 and 40
    - Women lose 8% of bone mass per decade, men 3%
  - The epiphyses, vertebrae, and jaws are most affected
    - Resulting in fragile limbs
    - Reduction in height
    - Tooth loss

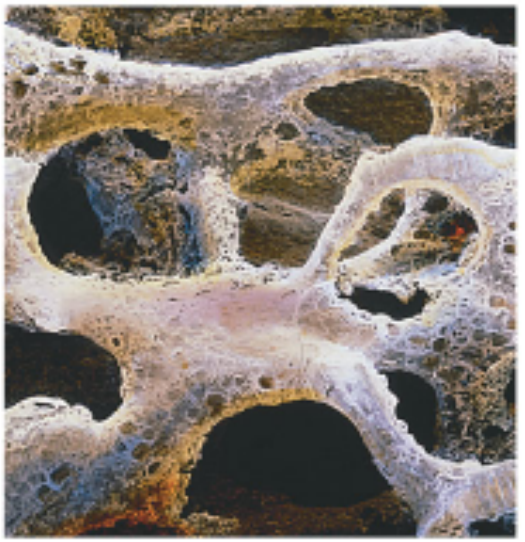
6-10 Effects of Aging on the Skeletal System

- Osteoporosis
  - Severe bone loss
  - Affects normal function
  - Over age 45, occurs in:
    - 29% of women
    - 18% of men

Figure 6-18 The Effects of Osteoporosis on Spongy Bone



Normal spongy bone SEM · 25



Spongy bone in osteoporosis SEM · 21

6-10 Effects of Aging on the Skeletal System

- Hormones and Bone Loss
  - Estrogens and androgens help maintain bone mass
  - Bone loss in women accelerates after menopause
- Cancer and Bone Loss
  - Cancerous tissues release osteoclast-activating factor
    - That stimulates osteoclasts
    - And produces severe osteoporosis