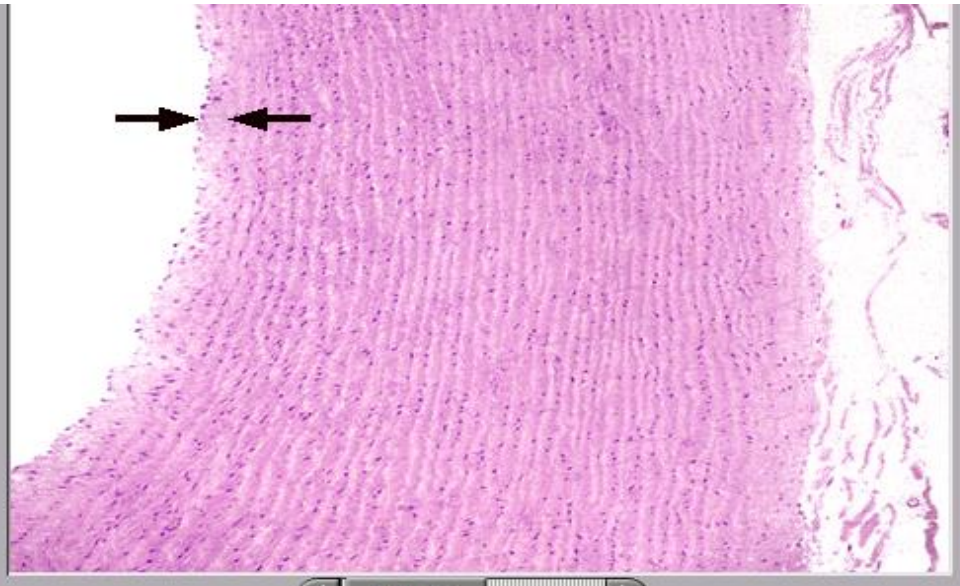
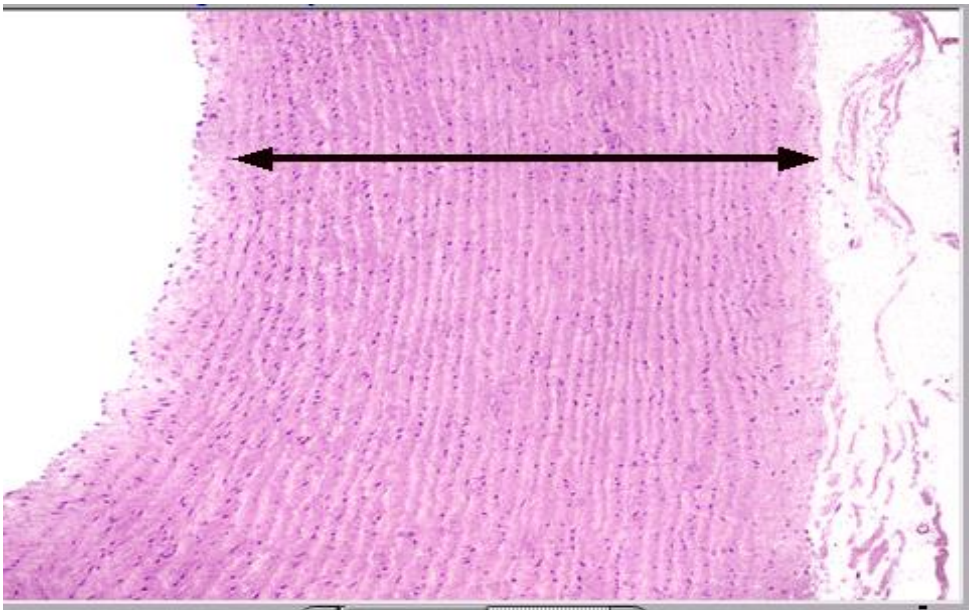


click to identify:

- Tunica intima
- Tunica media
- Elastic lamellae
- Smooth muscle
- Tunica adventitia

2 of 22

Large (elastic) artery -- Tunica intima of a large artery consists of an endothelium and underlying CT. An internal elastic lamina is not readily visible, because it blends with the elastic lamellae in tunica media. The thickest layer is tunica media, composed of circularly arranged smooth muscle cells and fenestrated elastic lamellae. Tunica adventitia is composed of connective tissue. 100x



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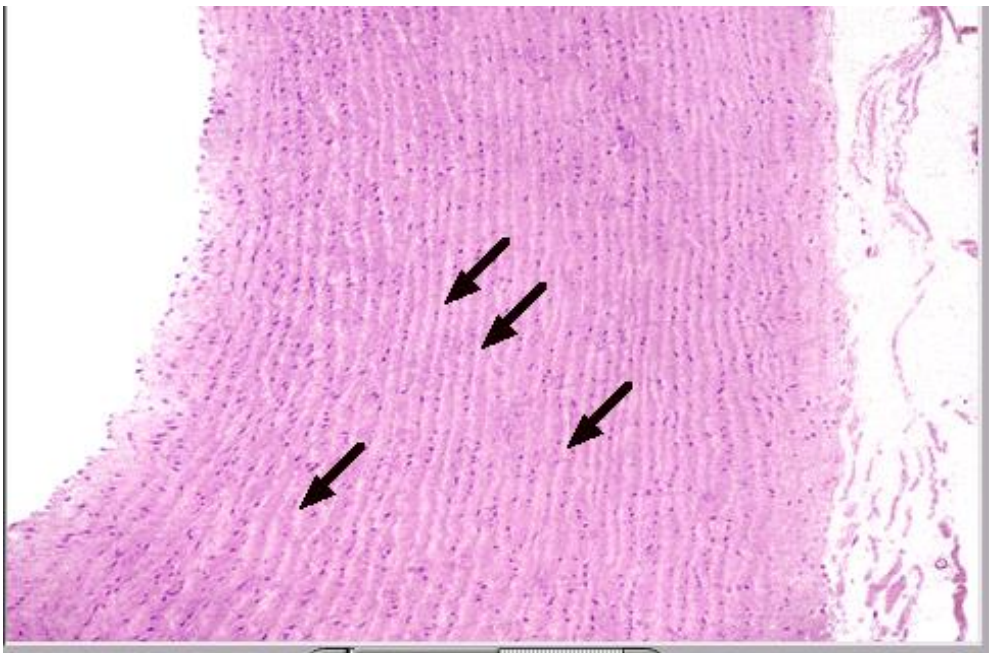

click to identify

Tunica intima
Tunica media
Elastic lamellae
Smooth muscle
Tunica adventitia

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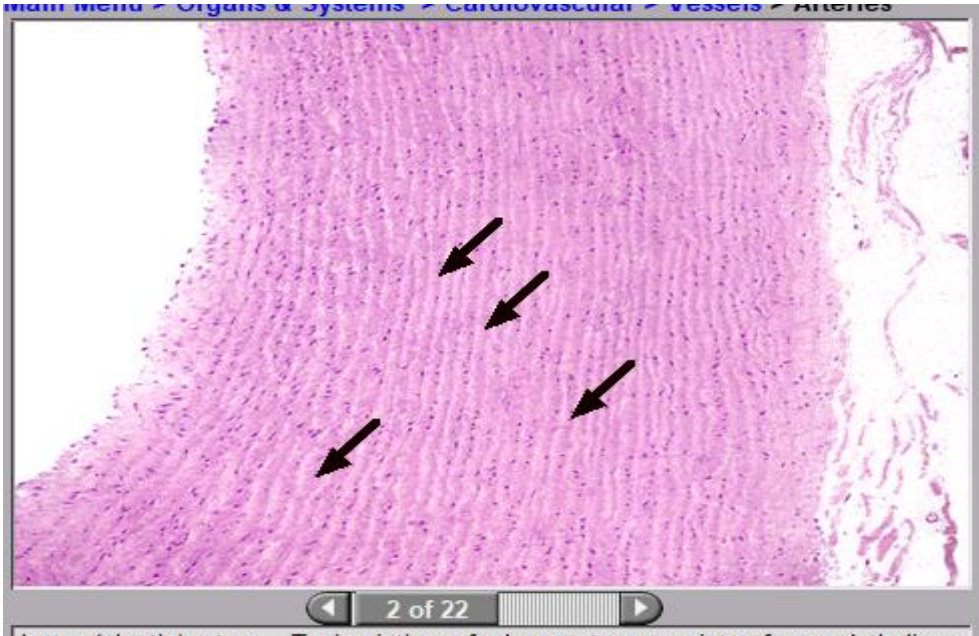

click to identify:

Tunica intima
Tunica media
Elastic lamellae
Smooth muscle
Tunica adventitia

2 of 22

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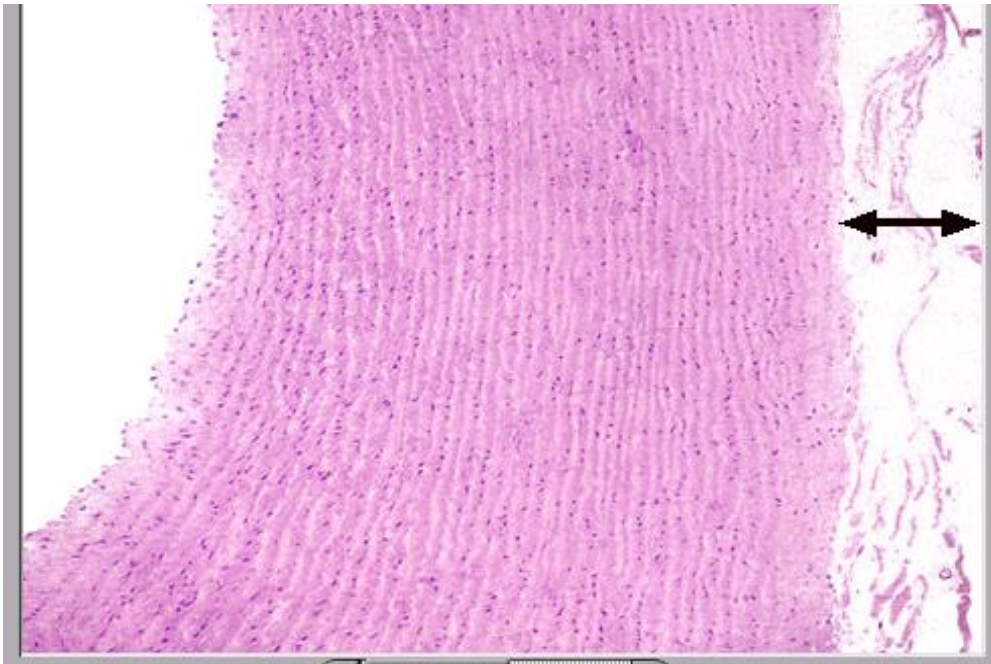

click to identify:

- Tunica intima
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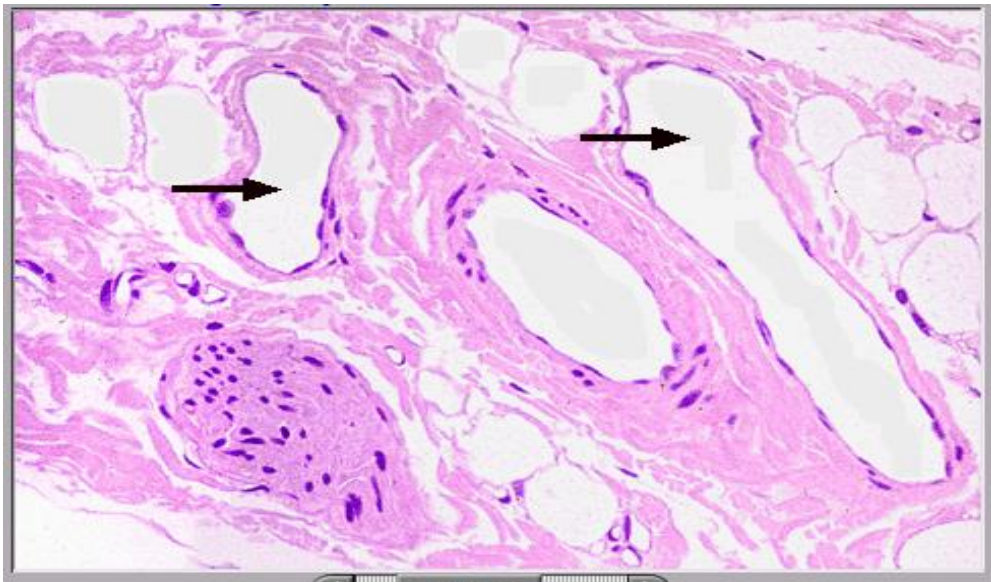
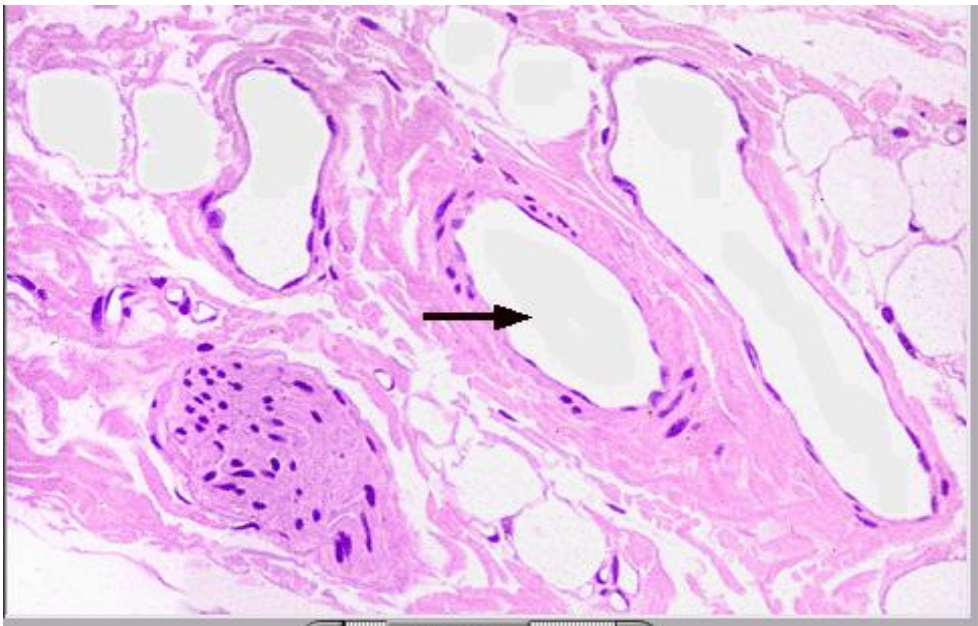


click to identify:

- › Venules
- Arteriole
- Capillaries
- Peripheral nerve

8 of 22

Large (elastic) artery -- Vasa vasorum are small blood vessels (arterioles, capillaries, and venules) in the walls of larger blood vessels that they supply. Vasa vasorum are most obvious in the tunica adventitia, but are also present in the outer tunica media. The tunica intima and inner tunica media are supplied by diffusion from the lumen of the larger vessel. 400x



click to identify:

- Venules
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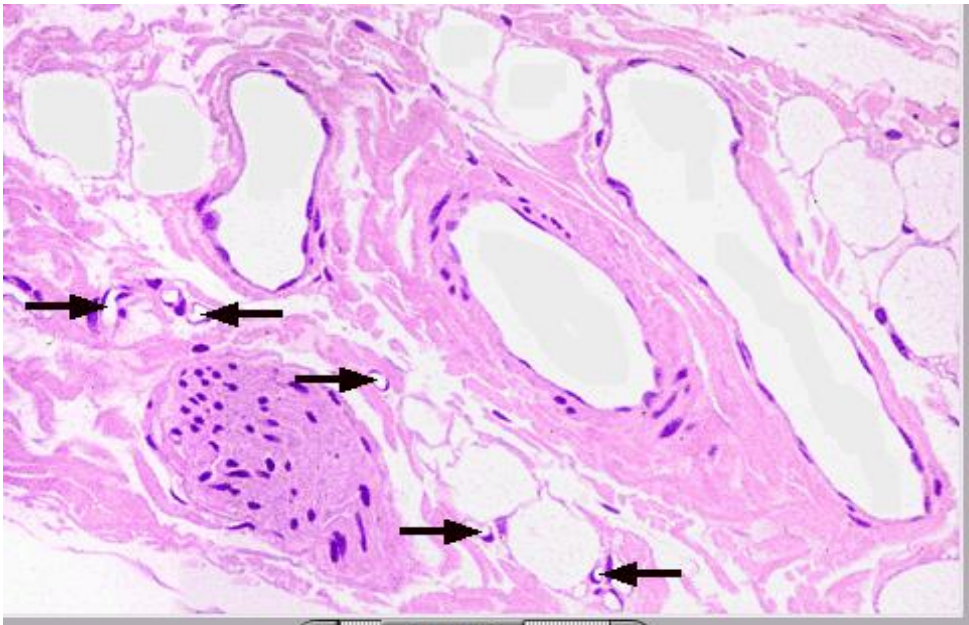

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- Capillaries
- Peripheral nerve

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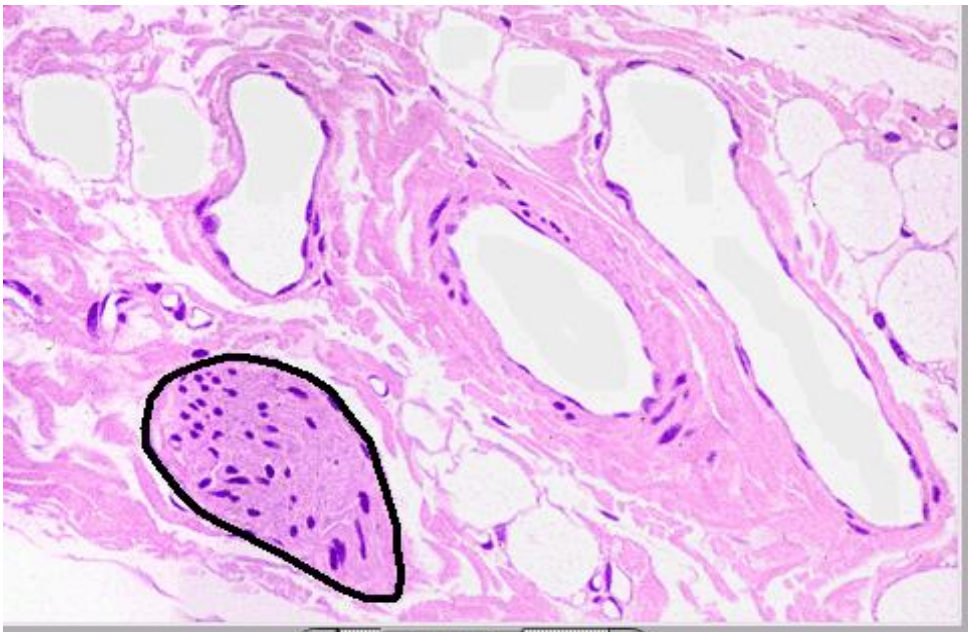

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click to identify:

- Venules
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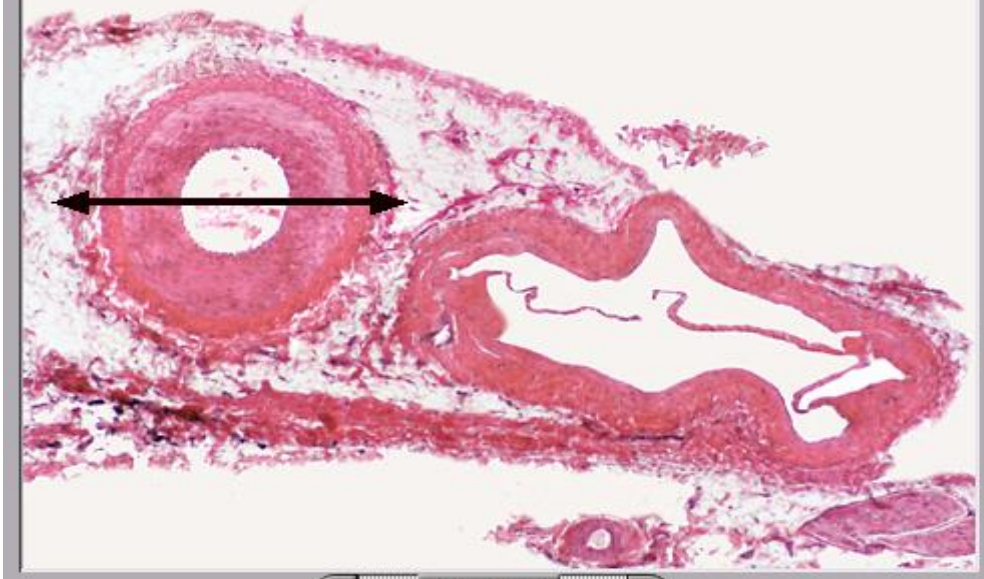
- > Peripheral nerve

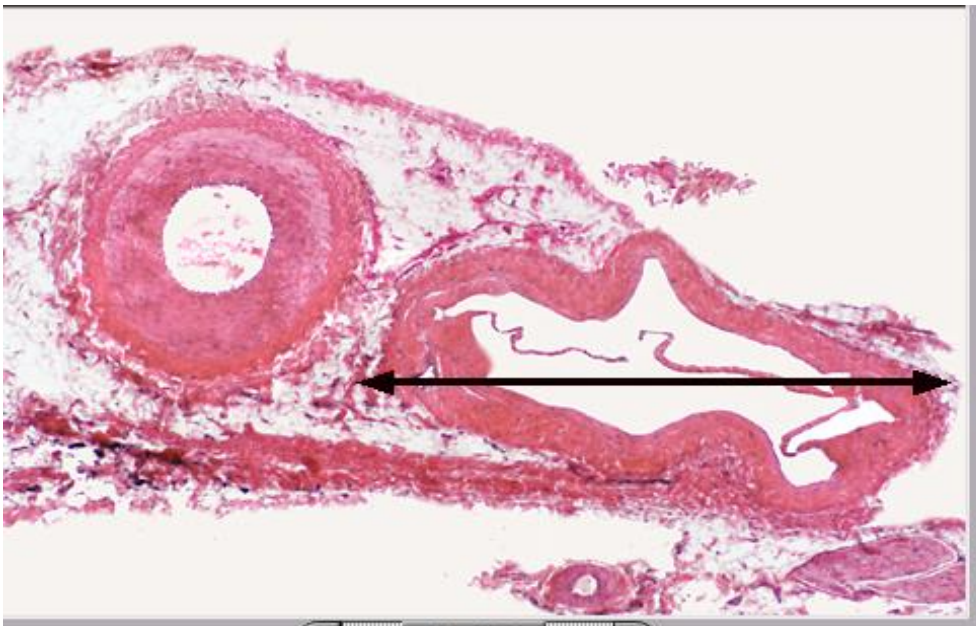


11 of 22

Medium artery and vein -- Arteries and veins of similar caliber often travel together. In this image compare the relative thicknesses of the tunica media (thicker in artery) and tunica adventitia (thicker in vein) in these medium-sized vessels. A valve is present in the medium vein; valves are not present in arteries. 40x

click to identify:

- > Medium artery
- Medium vein
- Tunica media
- Tunica adventitia
- Valve flap
- Peripheral nerve
- Small artery



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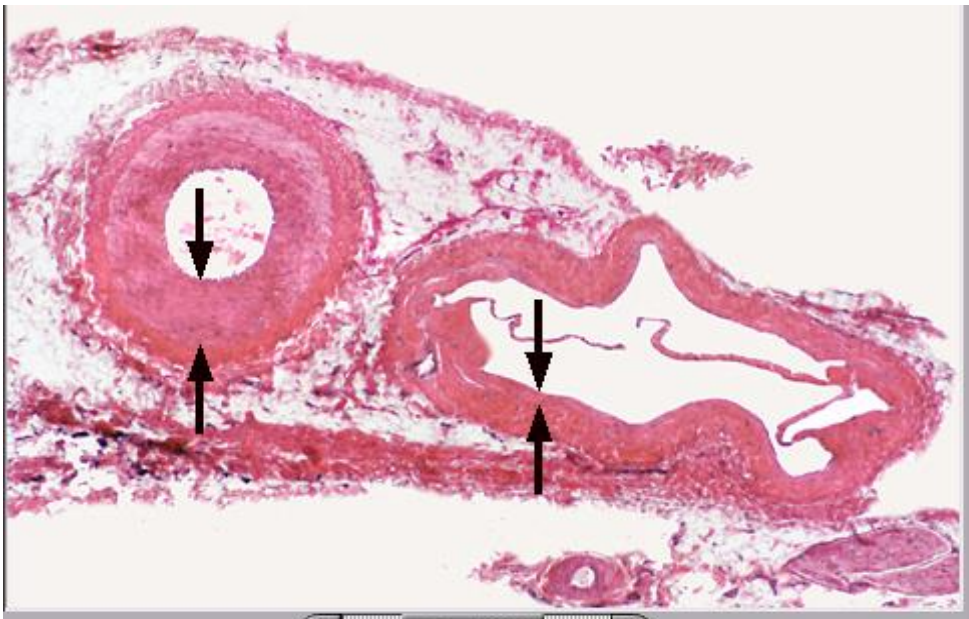

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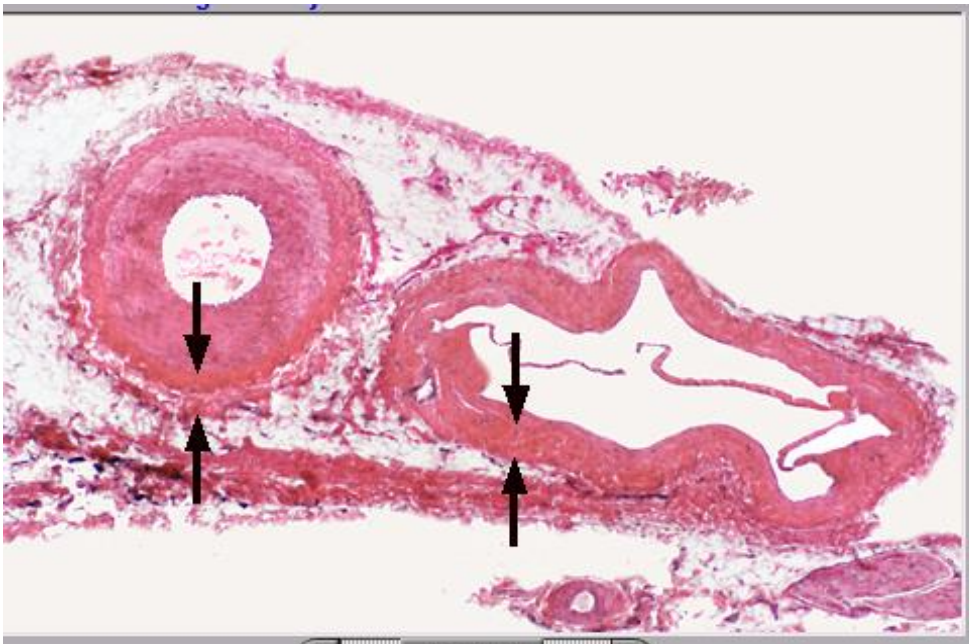

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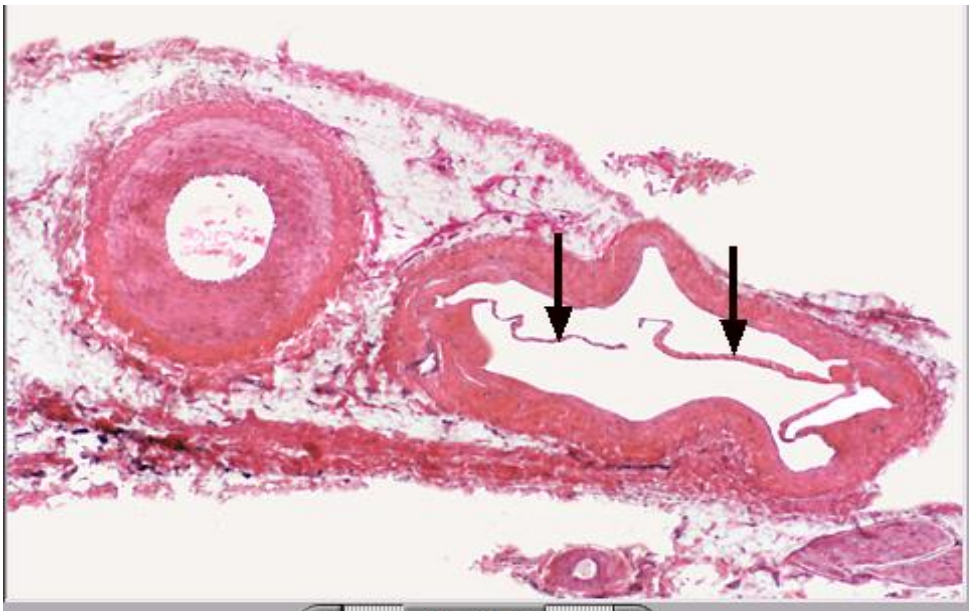

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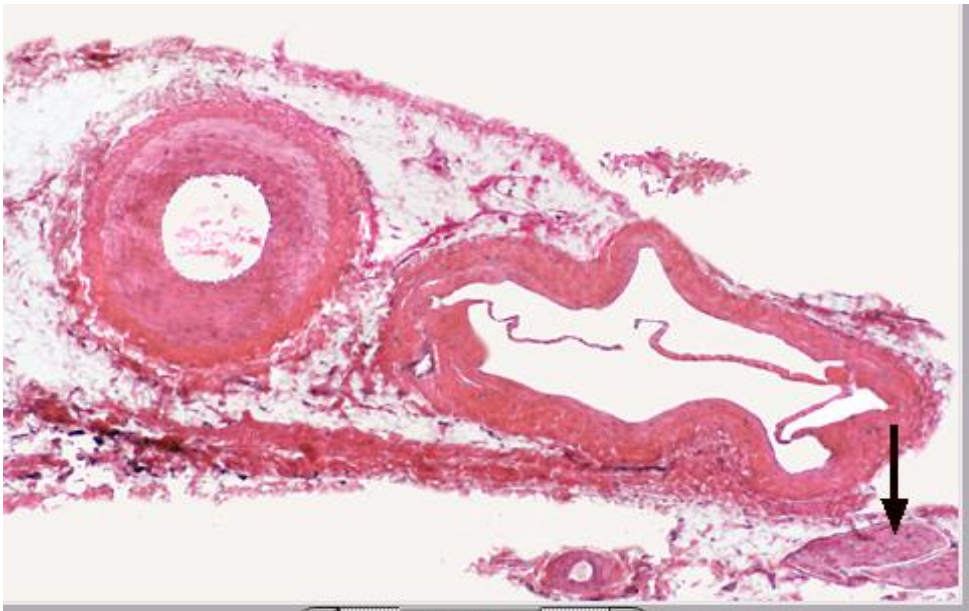

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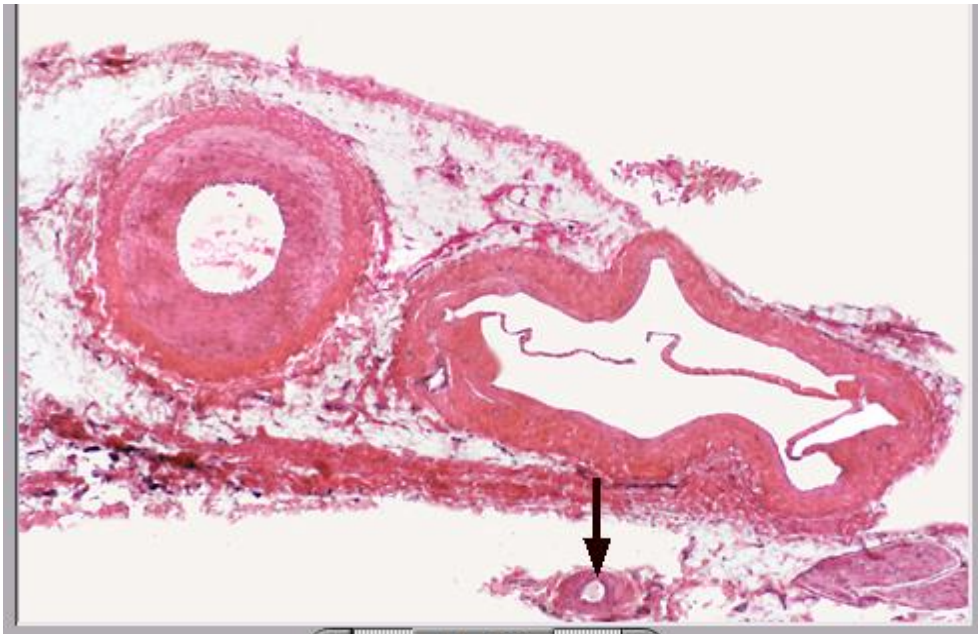

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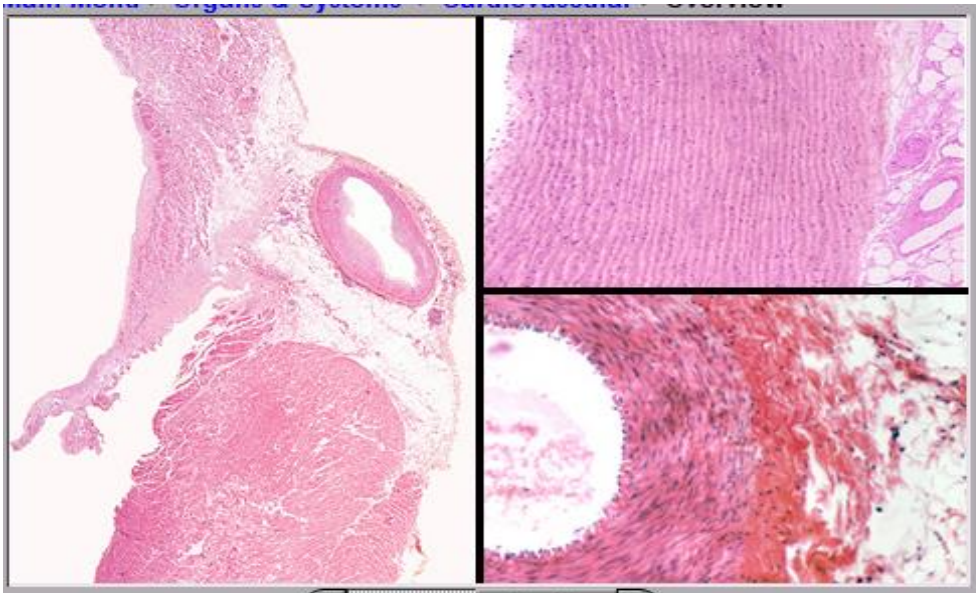
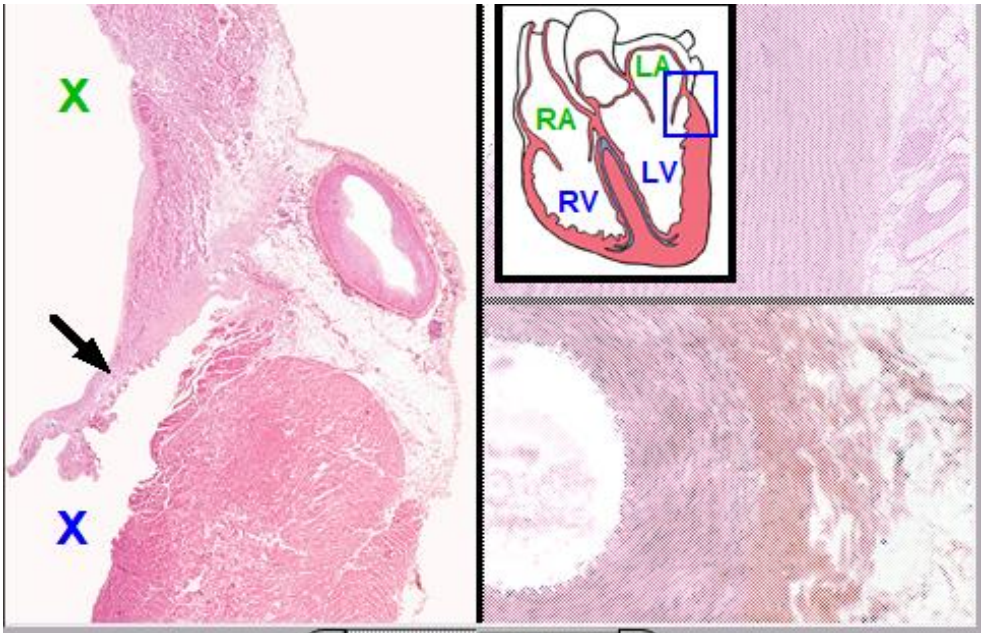


1 of 1

Overview -- The major subdivisions of the cardiovascular system include blood (a specialized CT), the heart (left image) which pumps the blood, and blood vessels (right images) that transport the blood. The heart and blood vessels are both composed of three tunics, each of which is similar in composition to, and continuous with, its counterpart in the other subdivision. 10X, 100X

click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

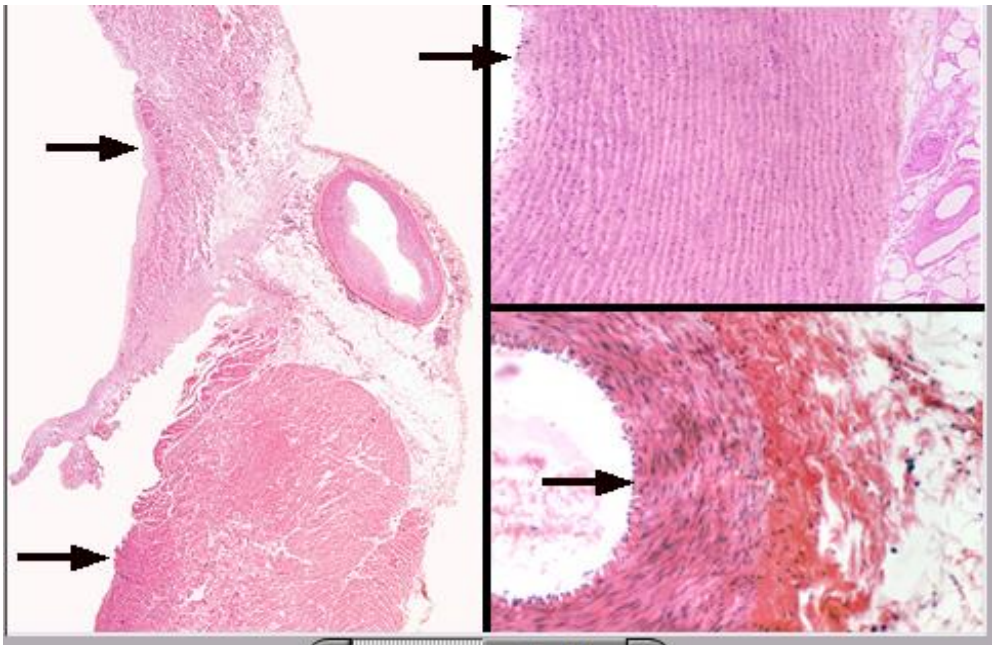


1 of 1

This section of the heart was taken from an area similar to that outlined by the blue rectangle in the illustration. The left atrium (green X) is the upper chamber; the left ventricle (blue X) is the lower chamber; a flap of the atrioventricular valve (arrow) separates the two chambers.

click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

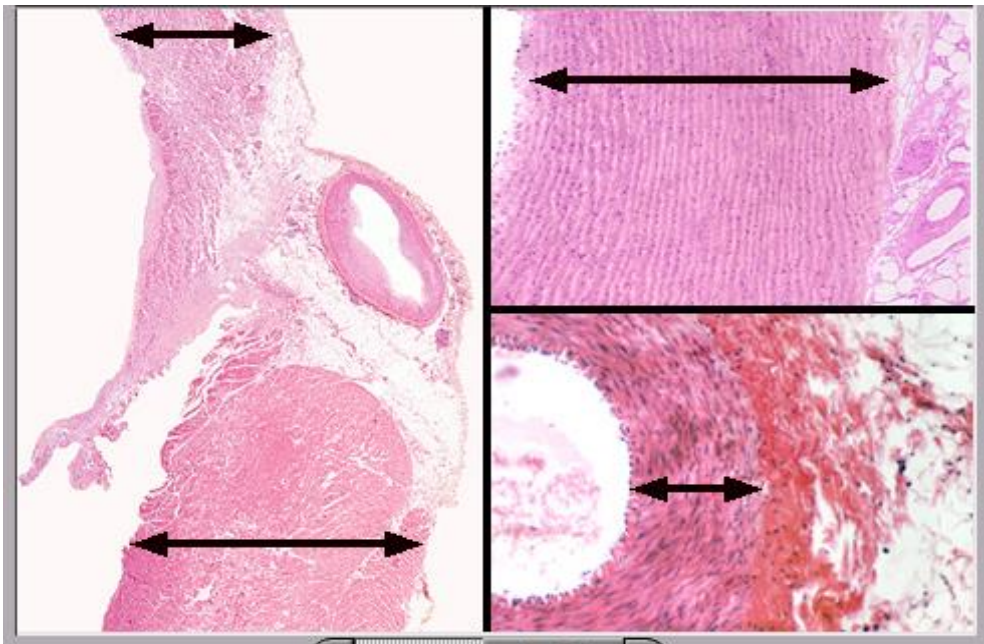


click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

1 of 1

The innermost tunic of either subdivision faces the blood and is called the endocardium in the heart and the tunica intima in blood vessels. In both subdivisions the innermost tunic is composed of a specialized simple squamous epithelium, called endothelium, and its underlying connective tissue.

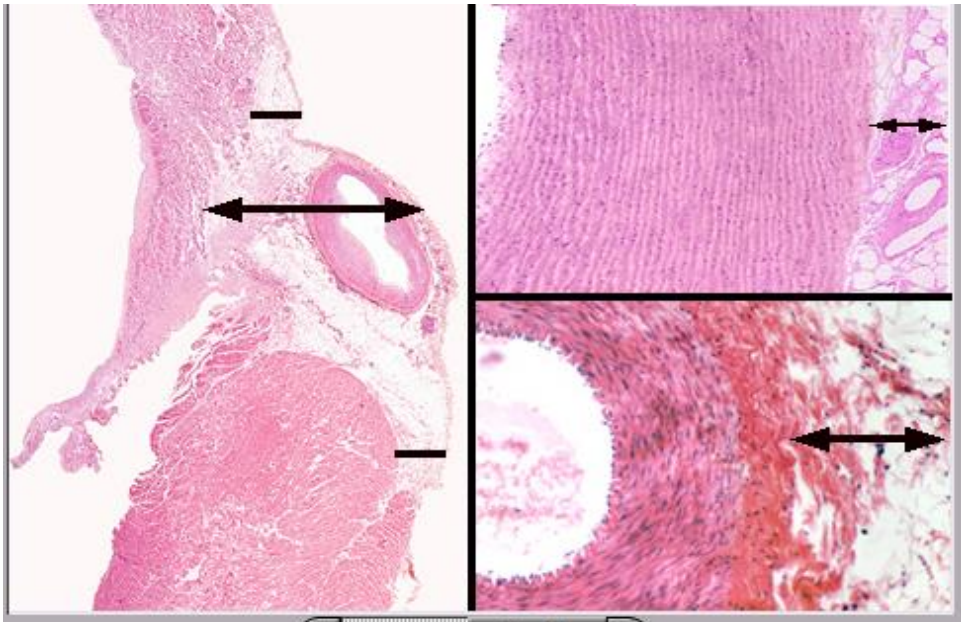


click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

1 of 1

The middle tunic of the heart is called the myocardium and is composed of cardiac muscle. In blood vessels the middle tunic is the tunica media and is composed of smooth muscle or smooth muscle plus connective tissue components.

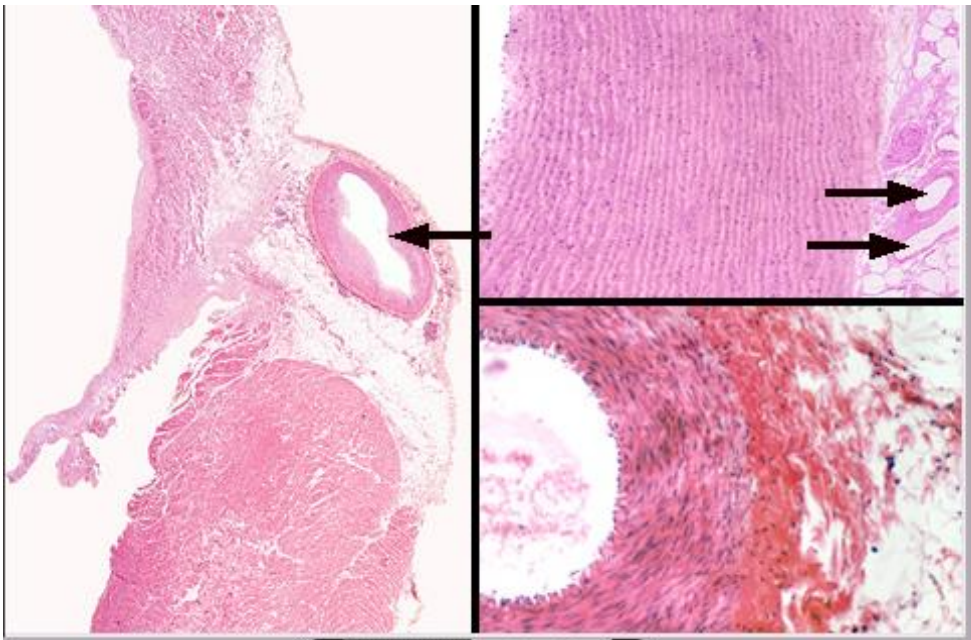


click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

1 of 1

The heart is suspended in an internal body cavity (pericardium), so its outer tunic is a serous membrane (epicardium). Like all serous membranes, epicardium is composed of a CT layer covered by a simple squamous epithelium (mesothelium). In blood vessels the outermost tunic is tunica adventitia, a CT layer, although smooth muscle is present in this tunic in large veins.

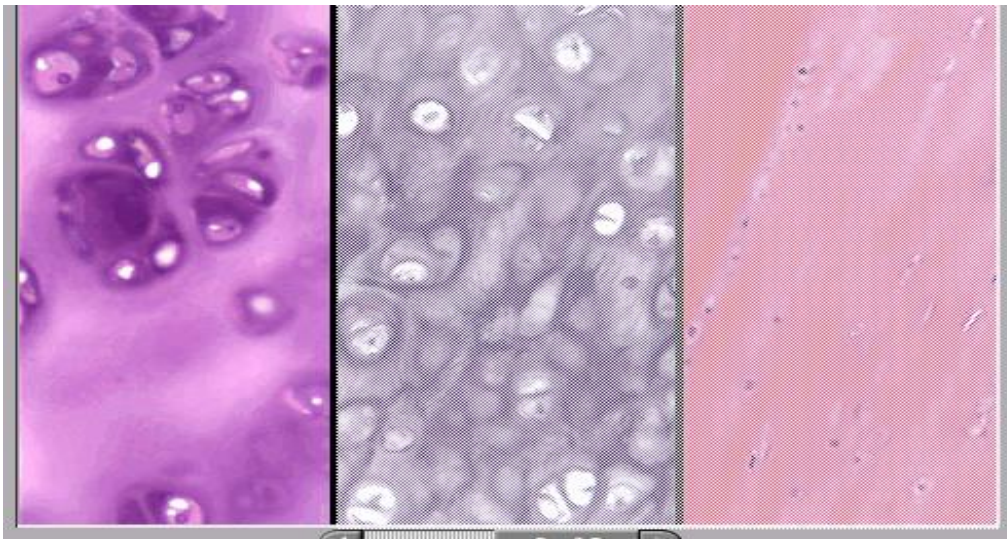


click to identify:

- Heart > components
- Inner tunic >
- Middle tunic >
- Outer tunic >
- Blood supply >

1 of 1

The heart and larger blood vessels are so large that they require their own blood supply, which is located in the outermost tunic of both subdivisions. Coronary vessels supply oxygen and nutrients to the heart while vasa vasorum ("vessels of the vessels") are the equivalent blood supply to the larger vessels.

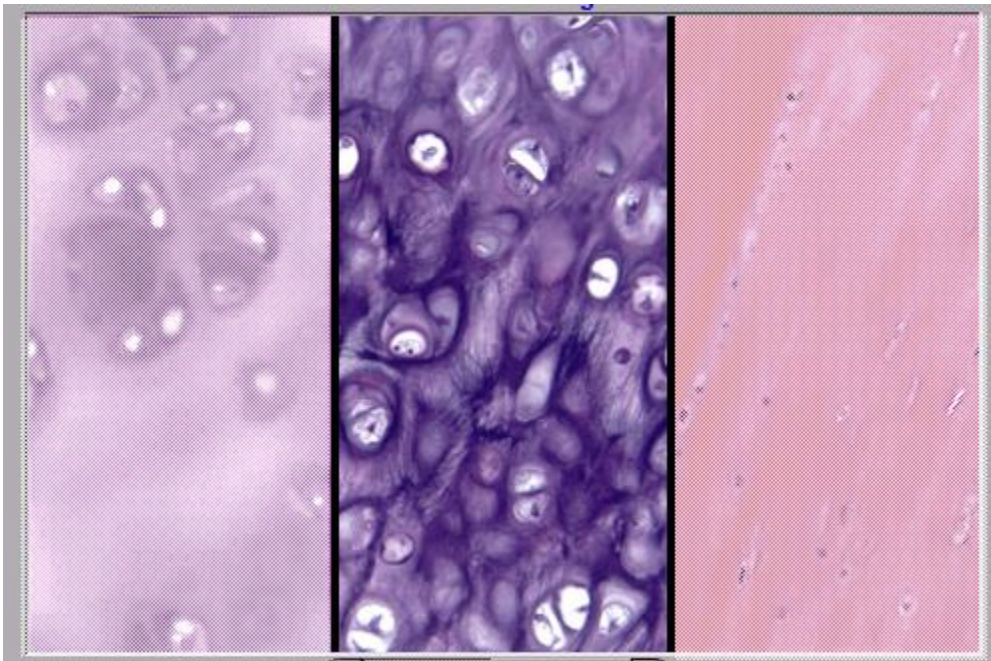


click to identify:

- Hyaline >
- Elastic >
- Fibrocartilage >

2 of 2

Hyaline is the most abundant cartilage type, with many chondrocytes, usually in isogenous groups. Abundant ground substance causes this cartilage to stain blue with hematoxylin. Collagen, the fibrillar component, is present as fibrils which are below the resolution of the light microscope and, therefore, not visible. Collagen is found in the nose, larynx, trachea, and as articular cartilages.

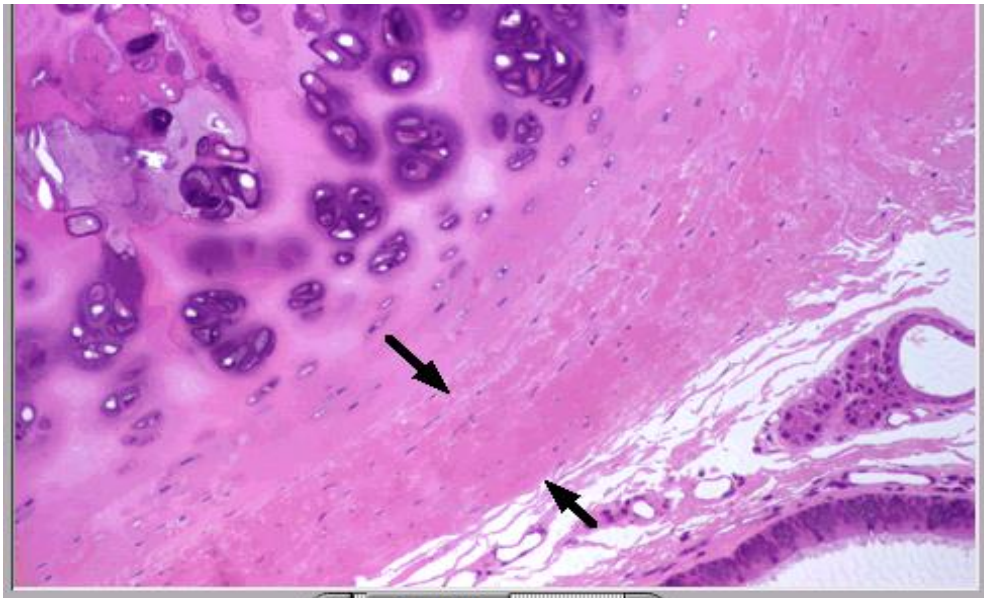


click to identify:

- Hyaline >
- Elastic >
- Fibrocartilage >

2 of 2

Elastic cartilage has more chondrocytes per unit volume than hyaline cartilage, but fewer isogenous groups. The most obvious feature of elastic cartilage is the abundant elastic fibers in its matrix, providing great flexibility. Elastic cartilage forms the pinna of the ear, the epiglottis and some of the minor laryngeal cartilages.

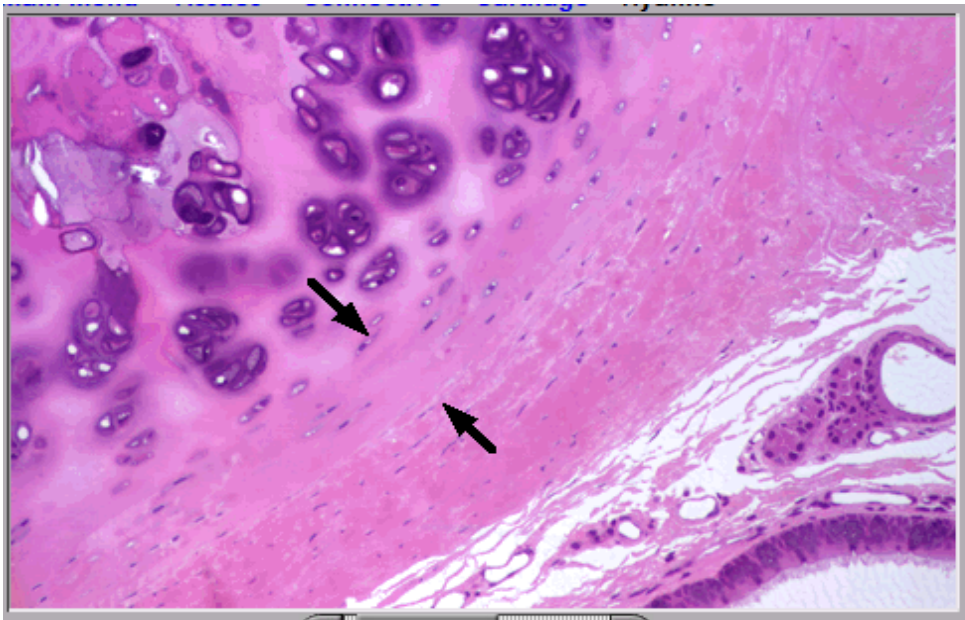


2 of 10

The fibrous layer of the perichondrium is composed of dense connective tissue proper and contains flattened, multipotential cells resembling fibroblasts. These cells round up and differentiate into chondroblasts located in the chondrogenic layer. The fibrous layer serves as a reserve-cell source for the chondrogenic layer and as protection for the cartilage.

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Hyaline cartilage >
- Epithelium >
- Next image

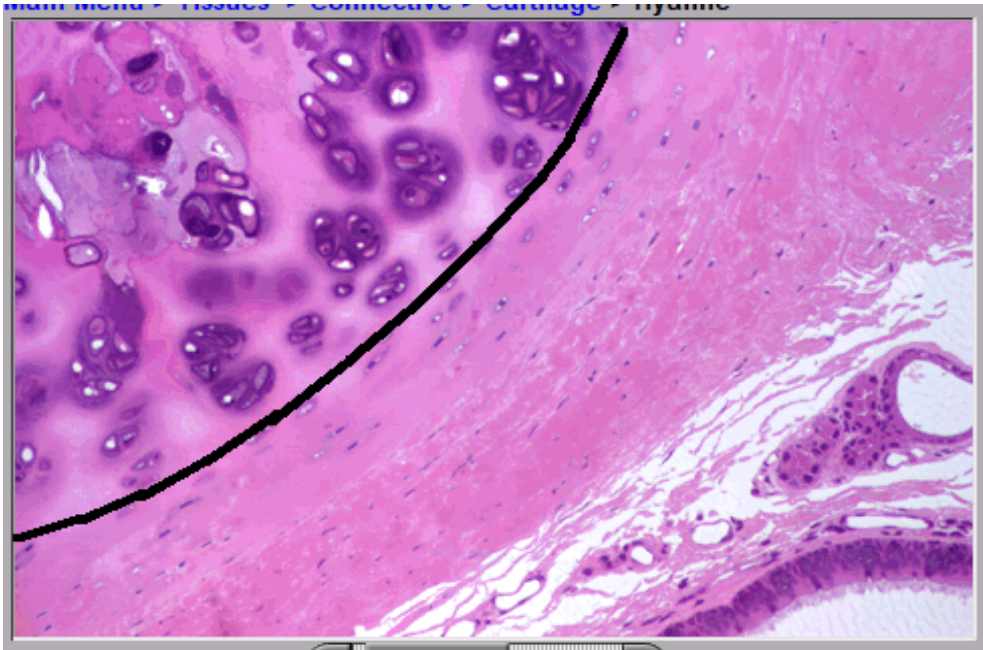


2 of 10

The chondrogenic layer of the perichondrium is interposed between the fibrous layer and cartilage tissue proper. This layer contains chondroblasts lying adjacent to the cartilage. Chondroblasts surround themselves with cartilage matrix, thus becoming chondrocytes and increasing the thickness of the cartilage by appositional growth.

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Hyaline cartilage >
- Epithelium >
- Next image

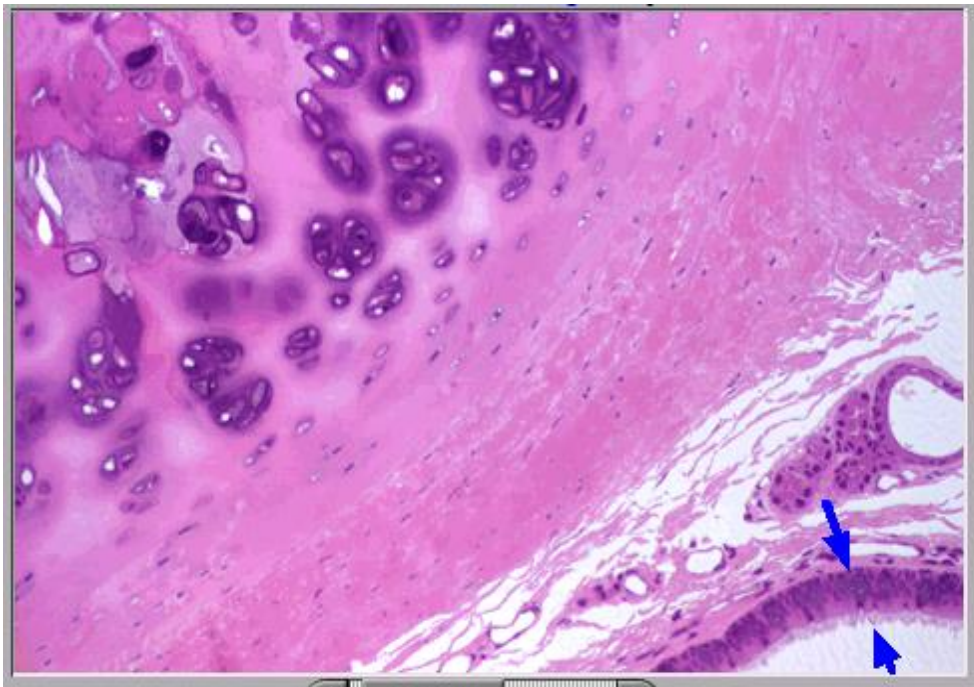


2 of 10

Hyaline cartilage proper is composed of cells (chondrocytes) and their surrounding extracellular matrix. Chondrocytes are usually present as isogenous groups. The glassy (hyaline) extracellular matrix is composed of a firm-rubber ground substance and collagen (type II) fibrils. The cartilage in the upper left corner was not well preserved during fixation of this tissue.

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Hyaline cartilage >
- Epithelium >
- Next image

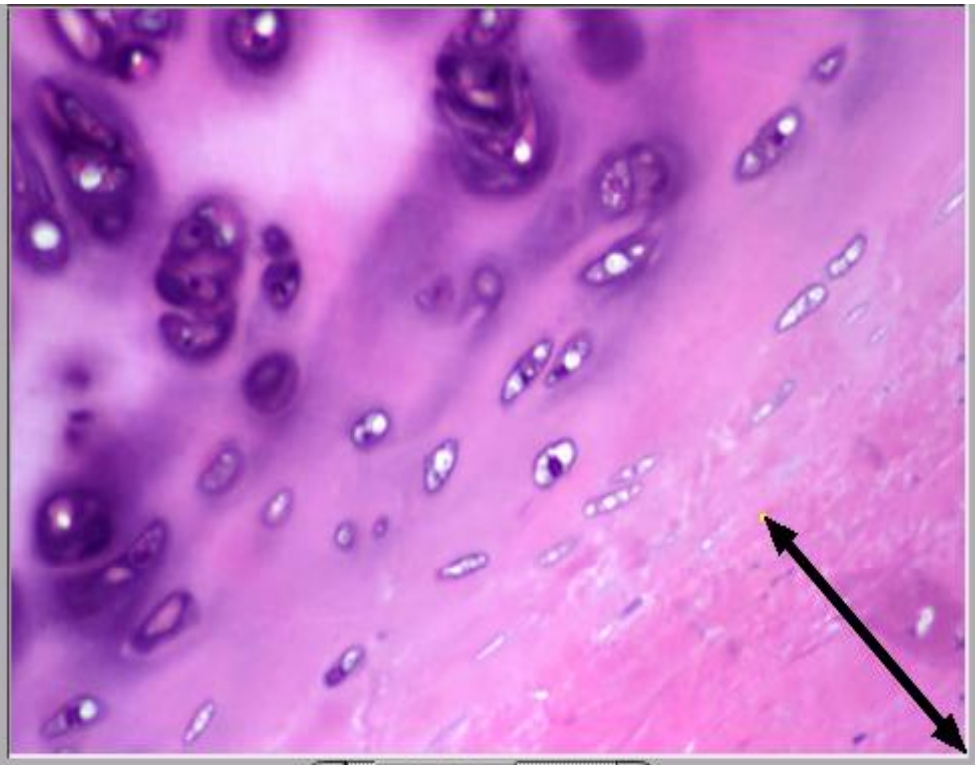


2 of 10

The epithelium lining the lumen in the lower right hand corner of the image is classified as pseudostratified columnar epithelium with cilia and goblet cells.

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Hyaline cartilage >
- Epithelium >
- Next image

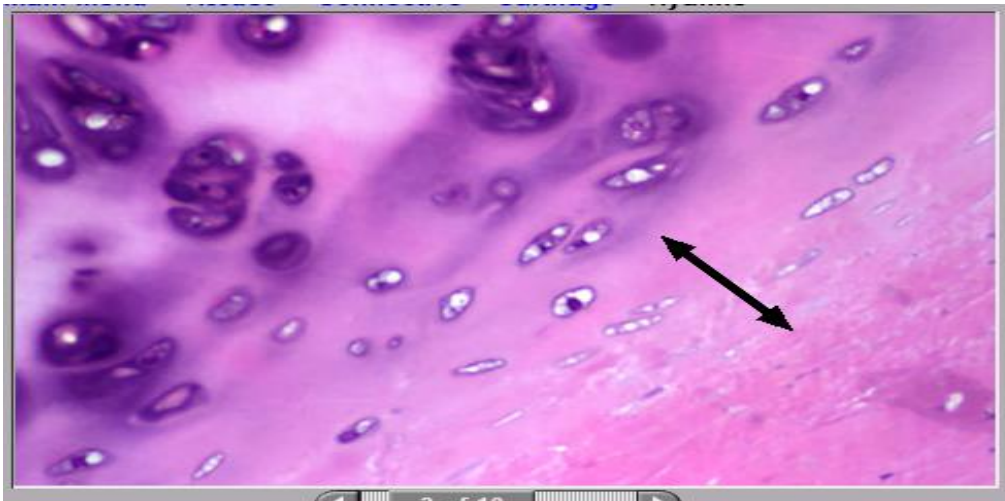


click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Chondroblasts
- Hyaline cartilage >
- Chondrocytes >
- Isogenous group

3 of 10

In the fibrous portion of the perichondrium, the nuclei of the cells resemble those of inactive fibroblasts. These cells are multipotential, however, and have the ability to differentiate into several types of adult connective tissue cells, including chondroblasts.

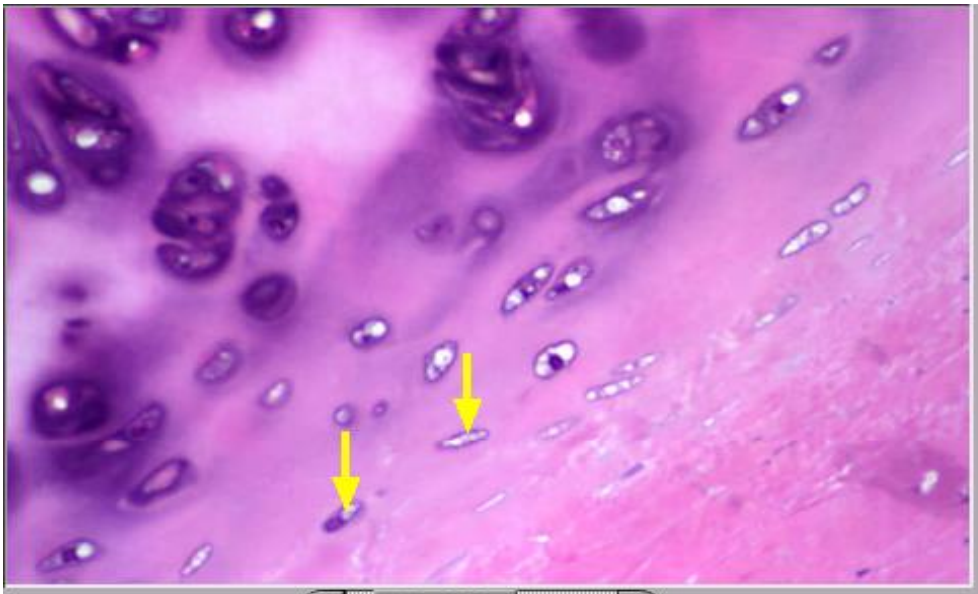


click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Chondroblasts
- Hyaline cartilage
- Chondrocytes >
- Isogenous group

3 of 10

Chondroblasts in the chondrogenic layer secrete cartilage matrix around themselves, becoming chondrocytes and increasing cartilage thickness by appositional growth. The exact point at which a chondroblast becomes a chondrocyte is hard to visualize. The transition, however, of inactive, flattened cells to plump, secretory chondroblasts to spherical chondrocytes is well shown.



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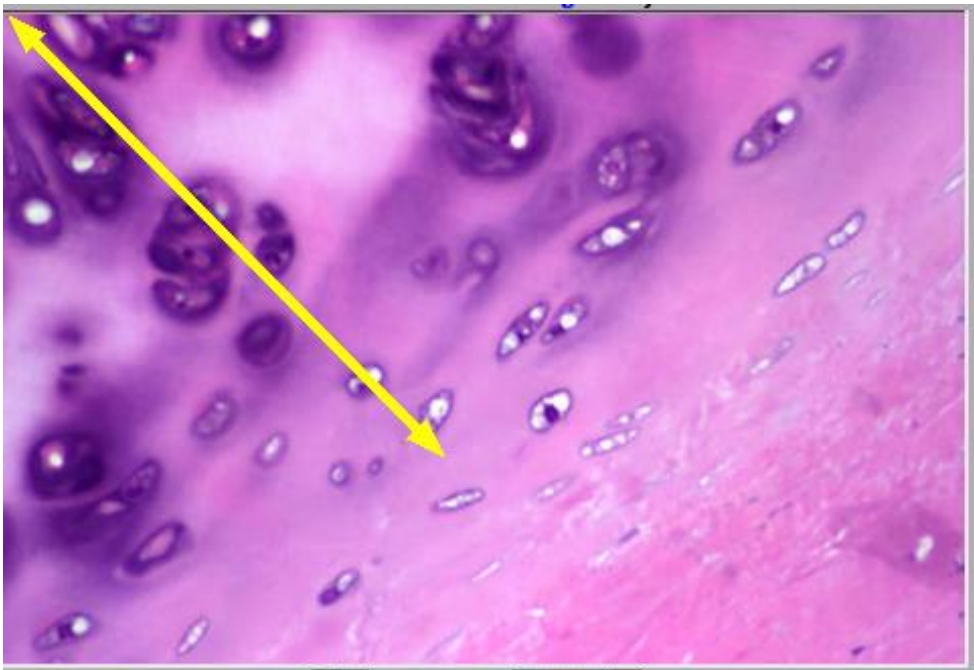
- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- > Chondroblasts
- Hyaline cartilage >
- Chondrocytes >
- Isogenous group

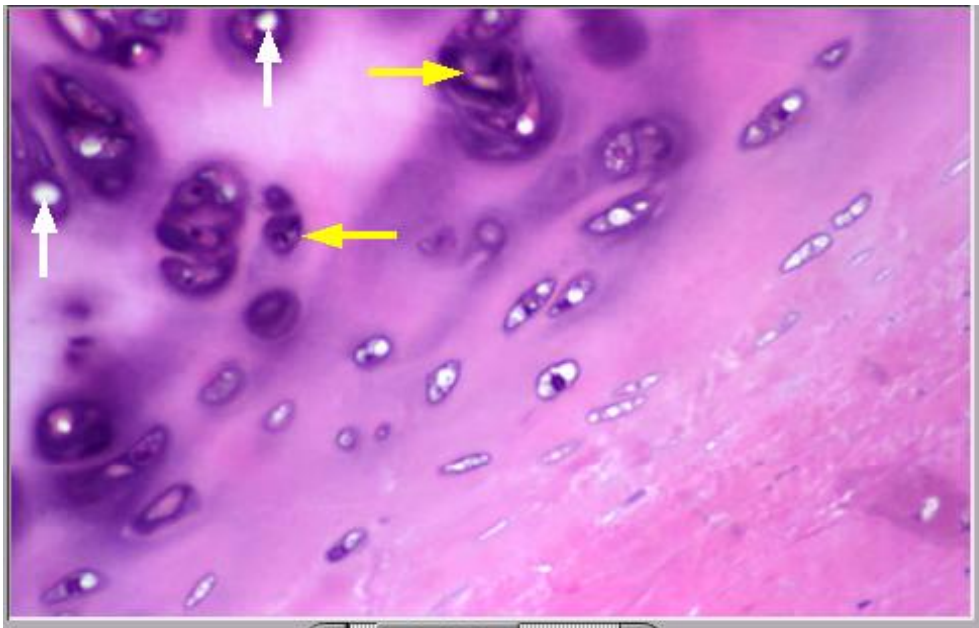


3 of 10

The mature hyaline cartilage is easily differentiated by its blue-purple appearance, glassy extracellular matrix, and clusters of cells. The exact position at which the chondrogenic layer becomes cartilage proper is difficult to pinpoint, however, because the two layers blend imperceptibly with each other.

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Chondroblasts
- > Hyaline cartilage >
- Chondrocytes >
- Isogenous group

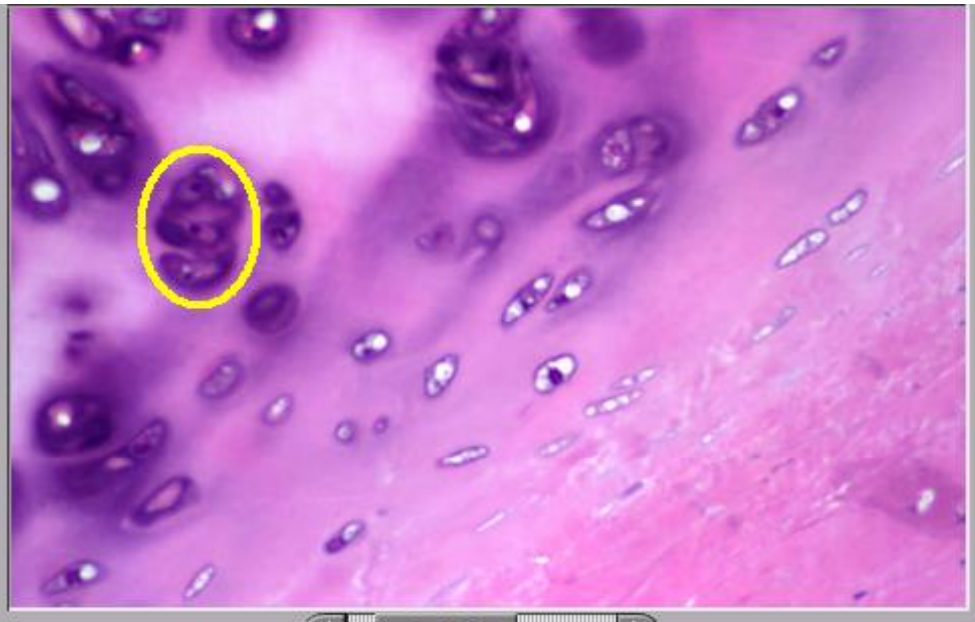


3 of 10

Chondrocytes (yellow arrows), chondroblasts that have completely surrounded themselves by matrix, lie in potential spaces called lacunae. Although surrounded by a firm, rubbery matrix that seems difficult to manipulate, chondrocytes produce matrix and divide (interstitial growth), forming isogenous groups. Clear spheres within these cells are lipid droplets (white arrows).

click to identify:

- Perichondrium: > fibrous layer
- Perichondrium: > chondrogenic layer
- Chondroblasts
- Hyaline cartilage >
- Chondrocytes >
- Isogenous group



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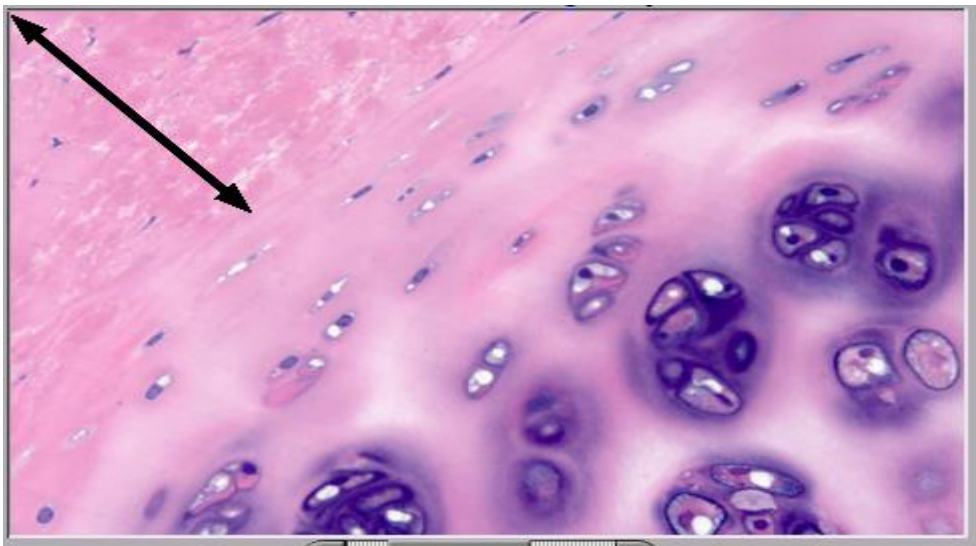
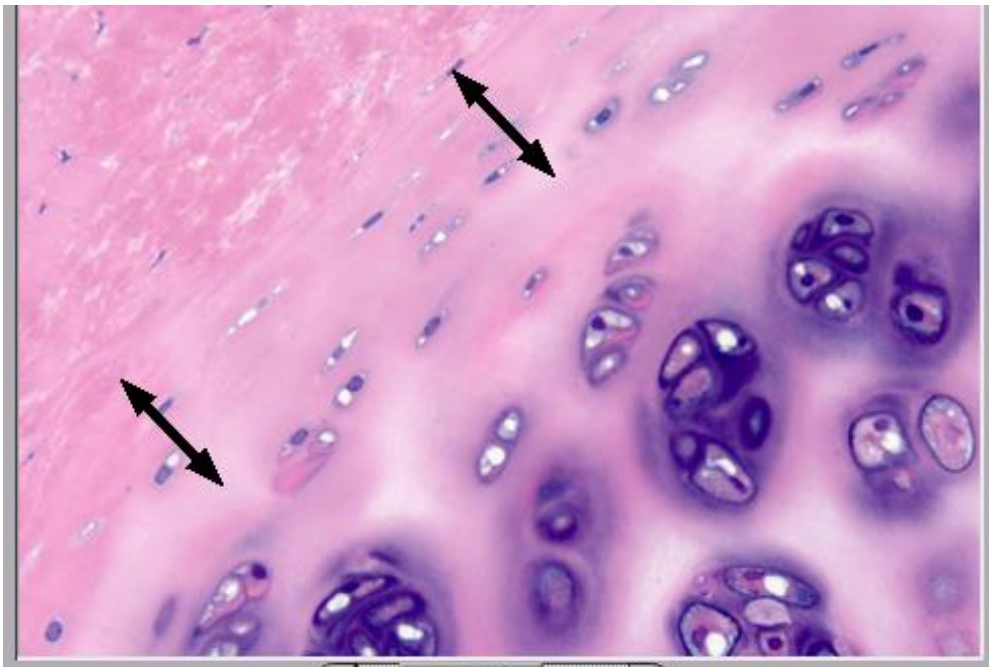


4 of 10

Hyaline cartilage -- Multipotential cells in the fibrous layer of the perichondrium differentiate into chondroblasts in the chondrogenic layer. When a chondroblast has surrounded itself with cartilage, it is then called a chondrocyte. A cluster of chondrocytes cloned from a single chondrocyte is an isogenous group, representing interstitial growth of this tissue. 400x

click to identify:

- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Hyaline cartilage
- Chondroblasts
- Chondrocytes
- Isogenous groups



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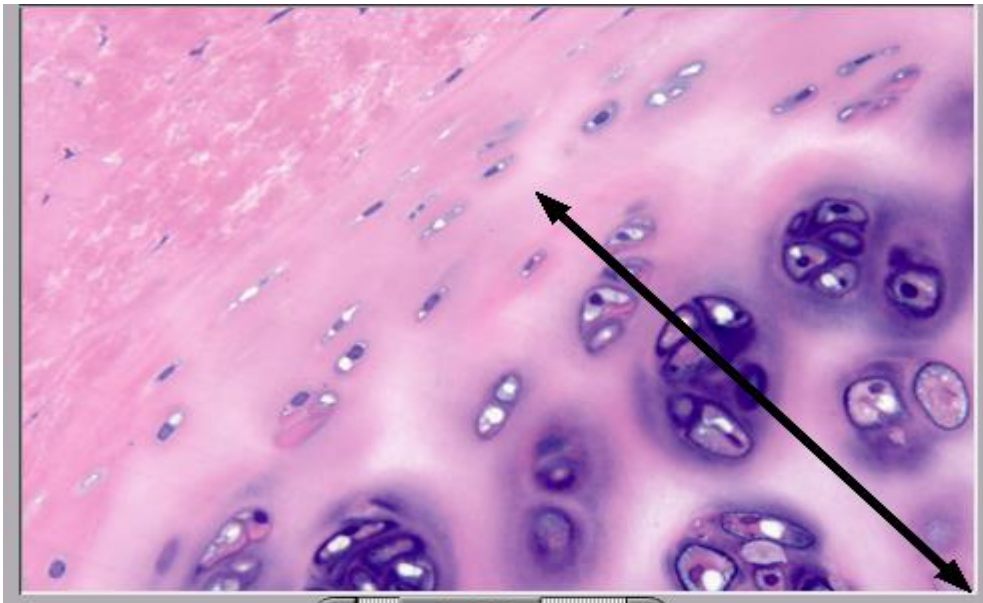

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- Perichondrium: chondrogenic layer
- › Hyaline cartilage
- Chondroblasts
- Chondrocytes
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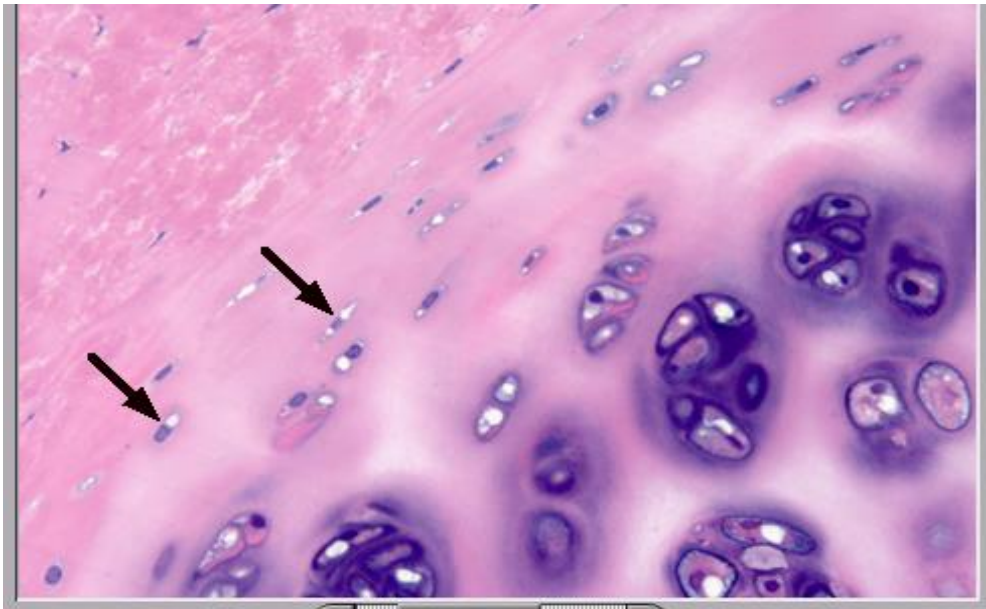

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- Hyaline cartilage
- › Chondroblasts
- Chondrocytes
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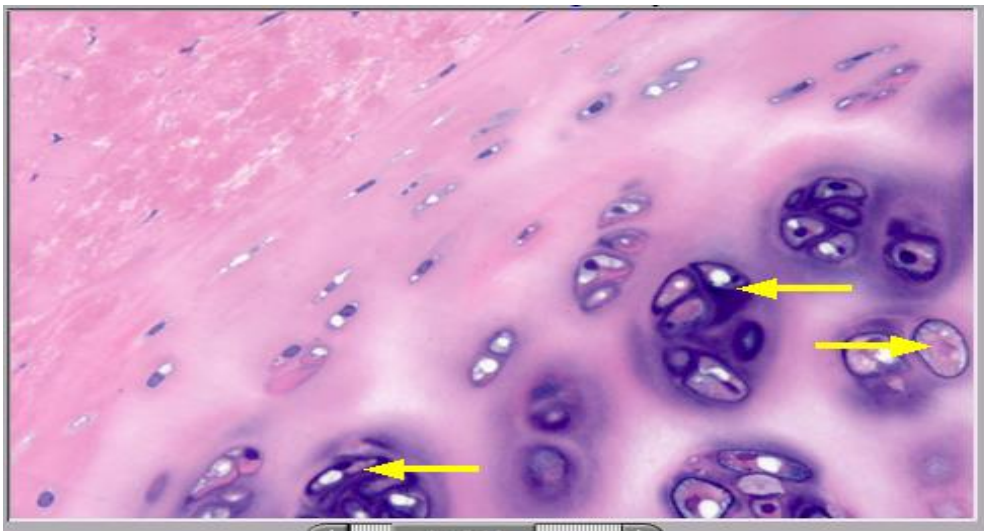

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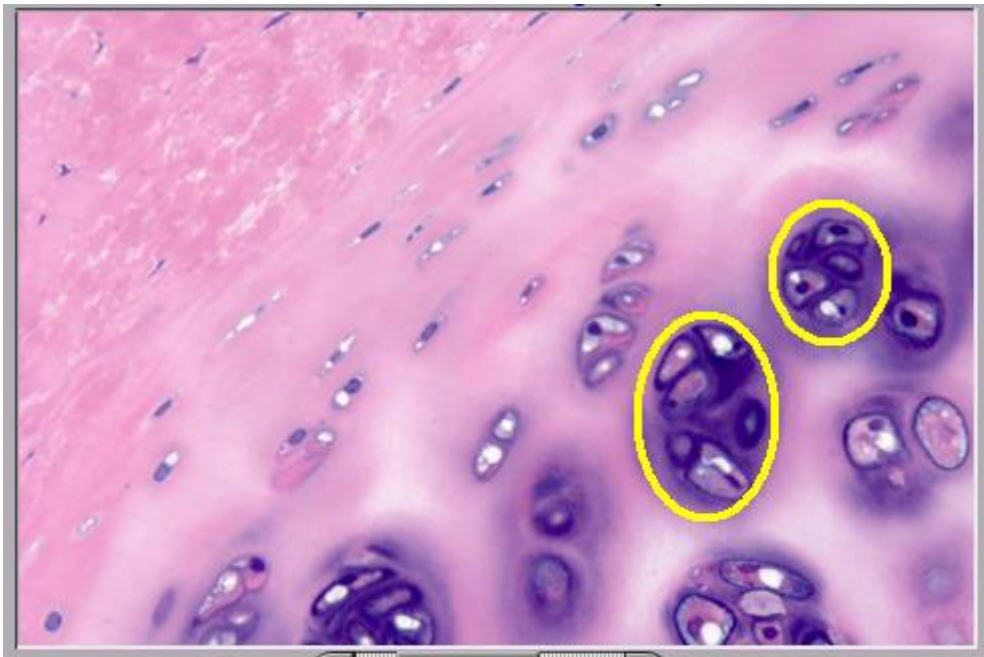

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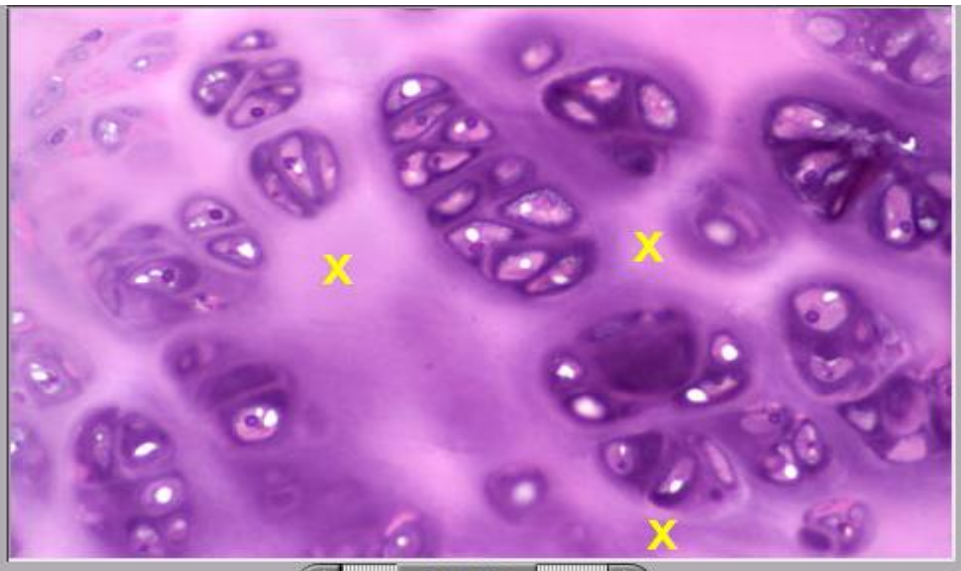
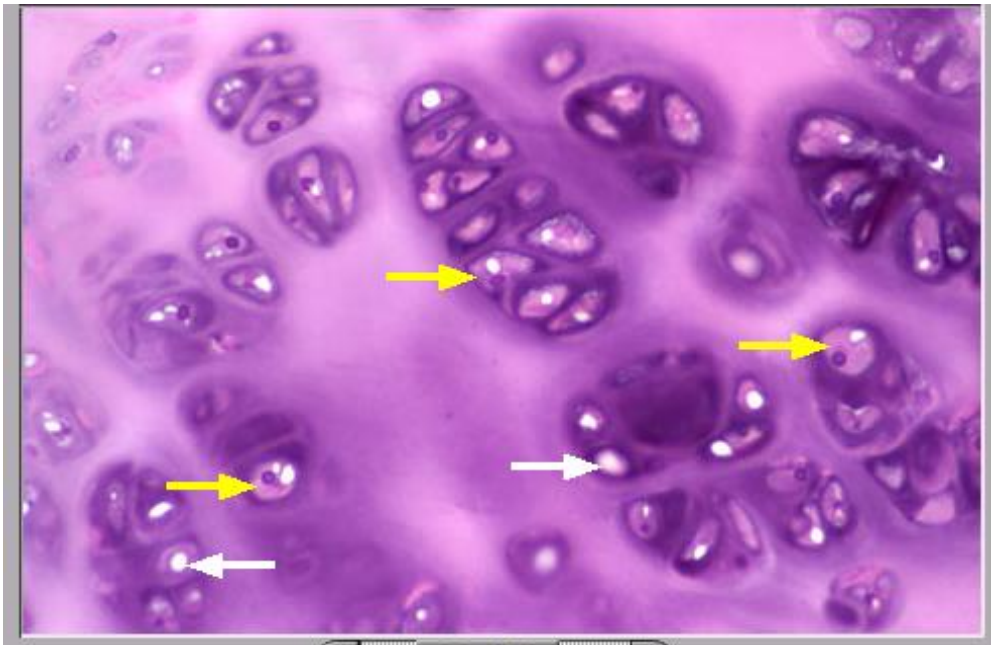


5 of 10

Hyaline cartilage -- Hyaline cartilage stains purple because of the high concentration of GAGs in its ground substance; collagen fibrils cannot be resolved with the light microscope. Each chondrocyte, lying in a potential space called a lacuna, can divide to form an isogenous group. No blood vessels are present, so nutrients diffuse through the cartilage to the chondrocytes. 400x

click to identify:

- Perichondrium: chondrogenic layer
- Extracellular matrix
- Chondrocytes >
- Isogenous groups
- Territorial matrix >
- Interterritorial matrix

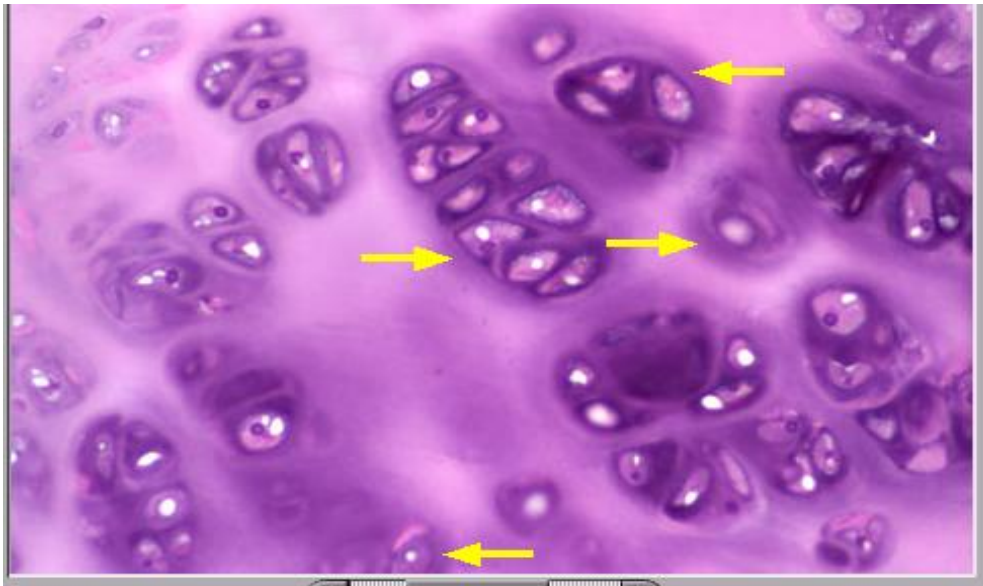


5 of 10

Chondrocytes (yellow arrows), lying in potential spaces called lacunae, are seen singly or in clusters called isogenous groups. These cells retain all the organelles of typical protein-producing cells and secrete matrix and divide throughout life, resulting in interstitial growth. Chondrocytes store nutrients, as evidenced by lipid droplets (white arrows) seen within their cytoplasm.

click to identify:

- Perichondrium: chondrogenic layer
- Extracellular matrix
- Chondrocytes >
- Isogenous groups
- Territorial matrix >
- Interterritorial matrix

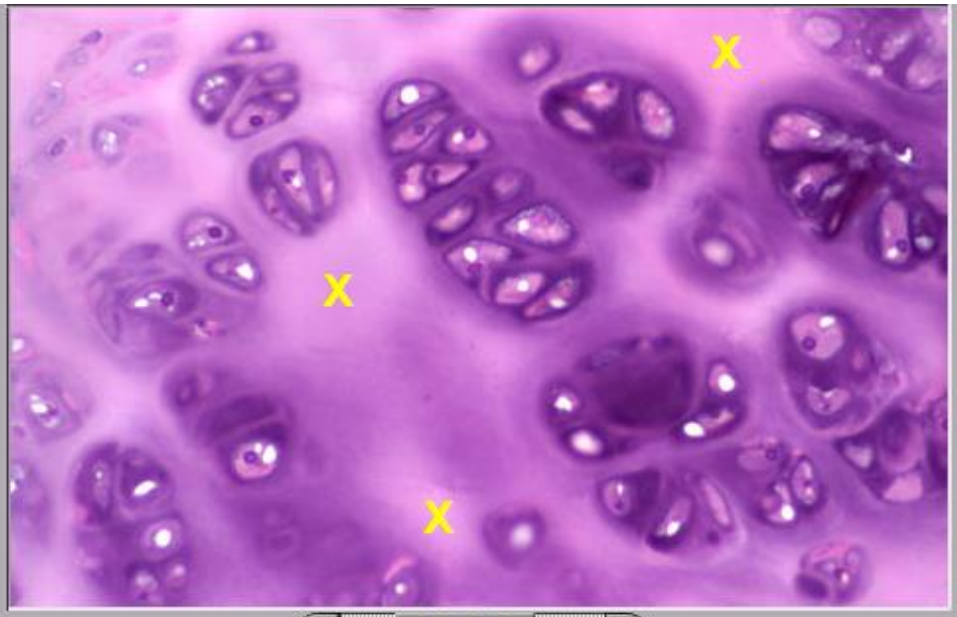


5 of 10

The darkly staining extracellular matrix immediately around an isogenous group is called the territorial matrix and represents an area where glycosaminoglycans are highly concentrated. Ground substance is less concentrated farther from a chondrocyte or an isogenous group and, consequently, stains less blue. This area is termed the interterritorial matrix.

click to identify:

- Perichondrium: chondrogenic layer
- Extracellular matrix
- Chondrocytes >
- Isogenous groups
- Territorial matrix >
- Interterritorial matrix



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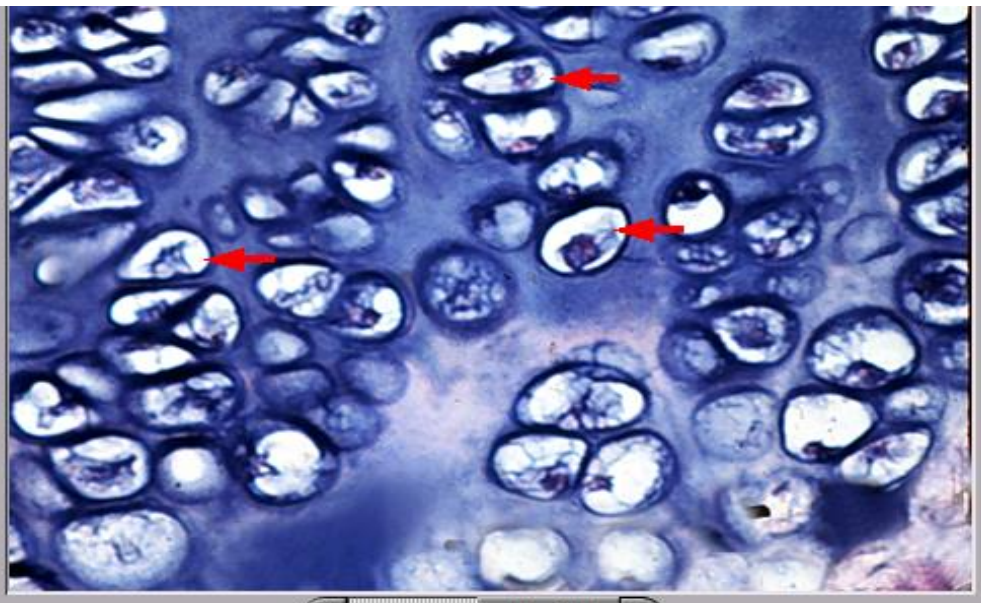
- Perichondrium: chondrogenic layer
- Extracellular matrix
- Chondrocytes >
- Isogenous groups
- Territorial matrix >
- Interterritorial matrix

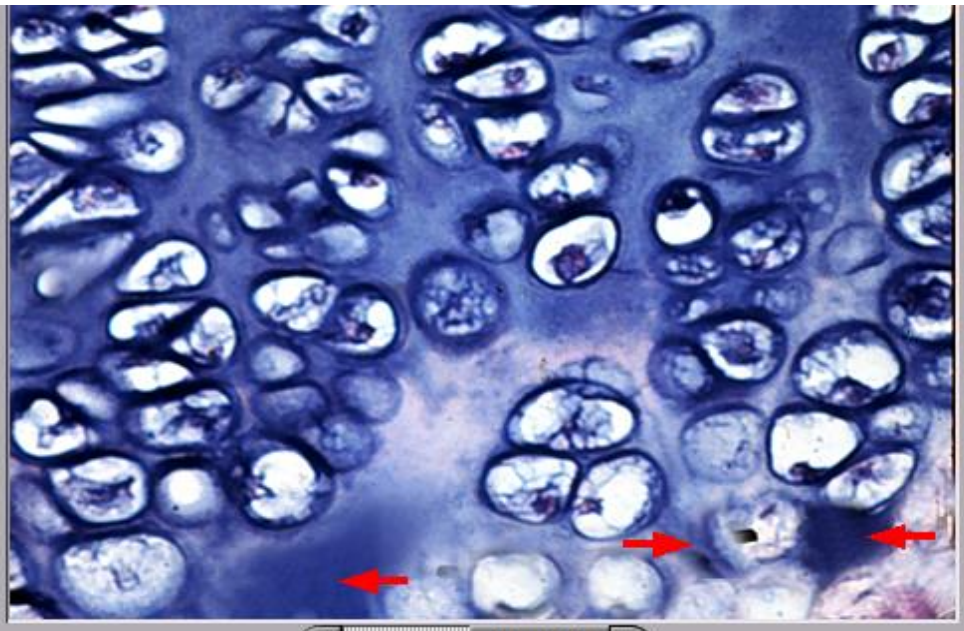


10 of 10

Degenerating cartilage cells enlarge (hypertrophy), mature, and secrete alkaline phosphatase, which facilitates calcification of the matrix. A calcified matrix prohibits diffusion of nutrients, so chondrocytes die, leaving empty lacunae surrounded by a calcified cartilage matrix. These regressive stages also occur in epiphyseal plates of growing long bones.

click to identify:

- Hypertrophy >
- Calcified cartilage matrix
- Empty lacunae



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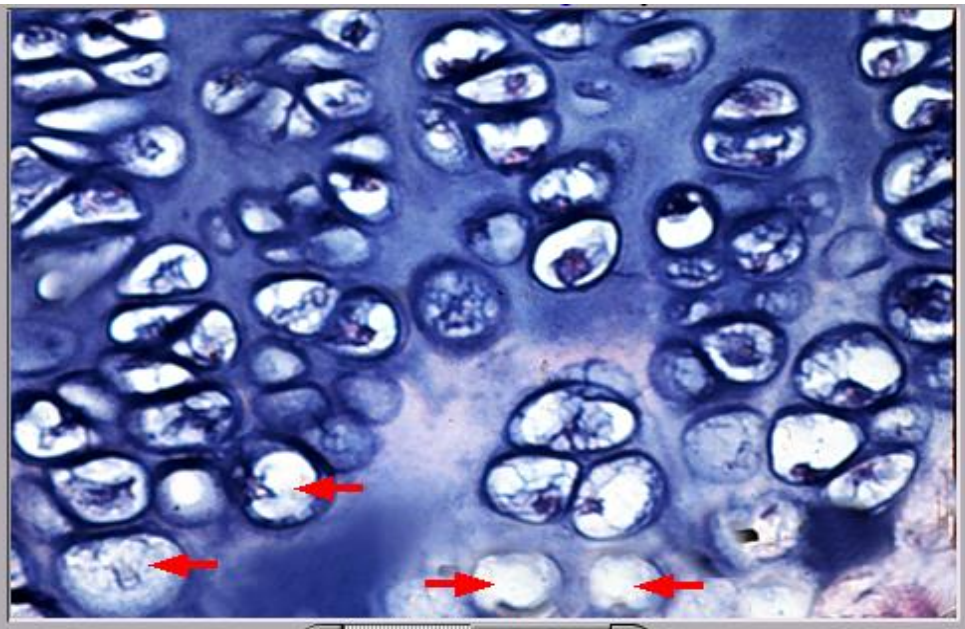

click to identify:

Hypertrophy >
Calcified cartilage matrix
> Empty lacunae

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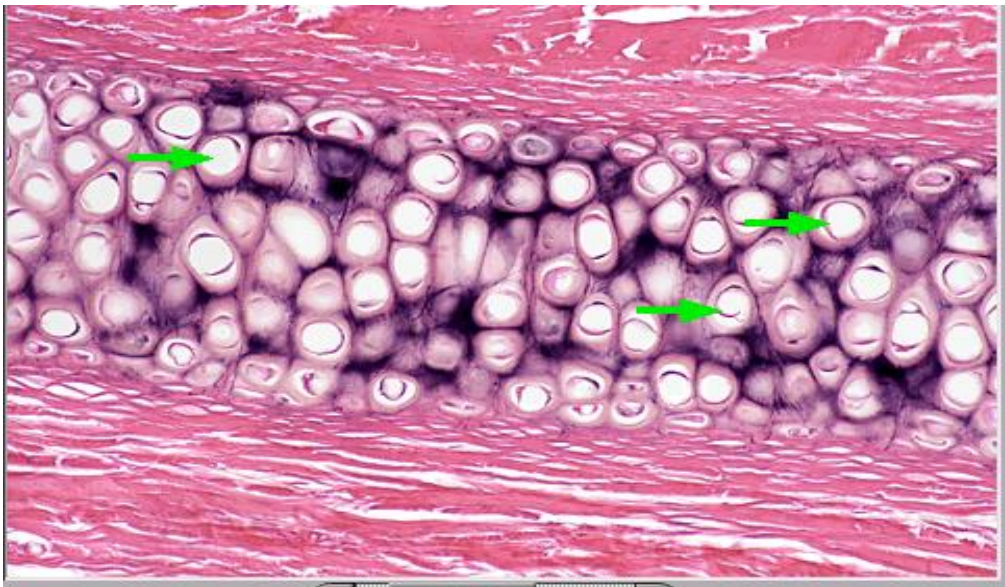
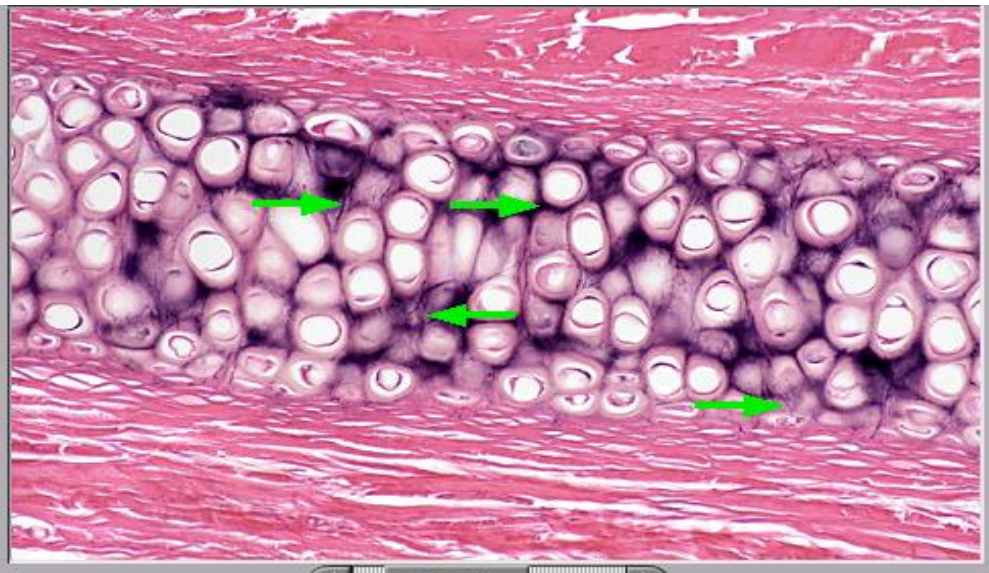


click to identify:

> Chondrocytes
Elastic fibers
Perichondrium: > chondrogenic layer
Chondroblasts
Perichondrium: > fibrous layer

2 of 5

Elastic cartilage -- Chondrocytes in elastic cartilage are larger and more numerous than in hyaline cartilage and form fewer isogenous groups. The extracellular matrix of elastic cartilage is less abundant than in hyaline cartilage. A special stain demonstrates the abundant elastic fibers in the matrix. No nuclei are stained in this preparation. 100x



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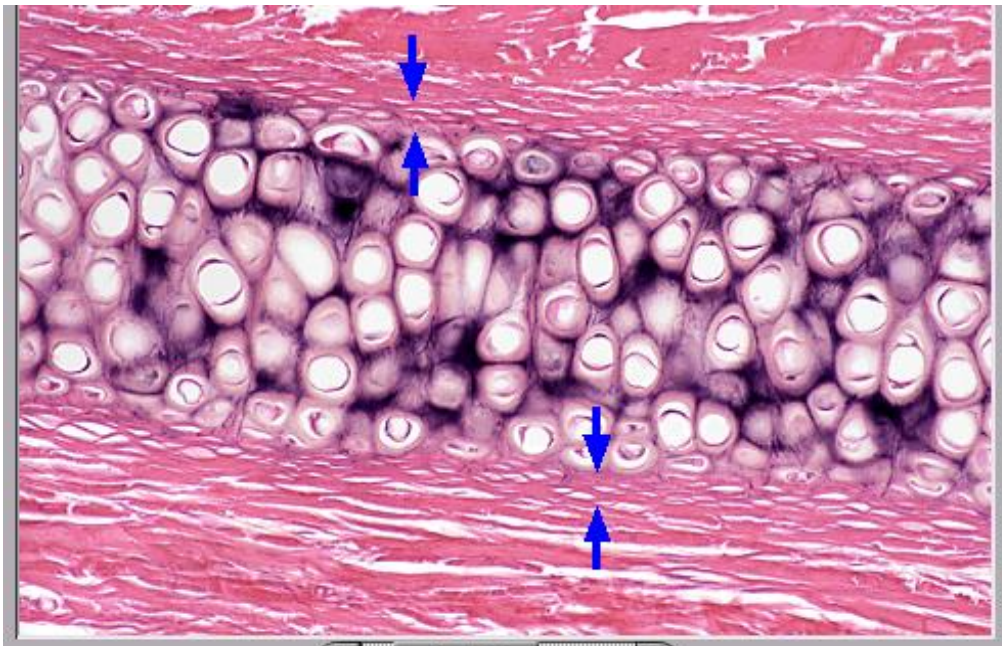
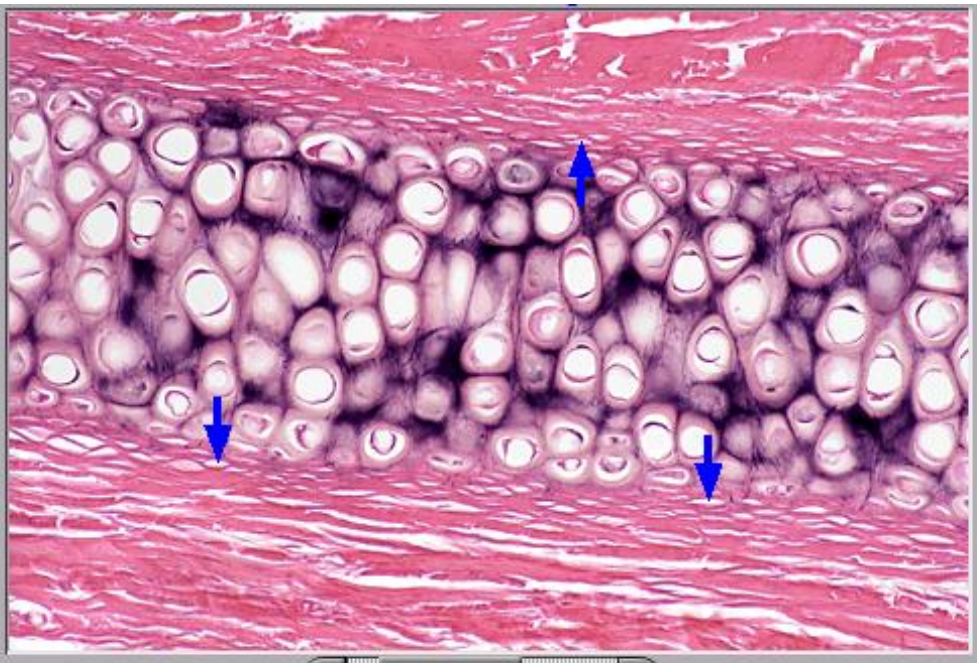


click to identify:

- Chondrocytes
- Elastic fibers
- Perichondrium: > chondrogenic layer
- Chondroblasts
- Perichondrium: > fibrous layer

2 of 5

Perichondrium surrounds elastic cartilage. The inner portion, the chondrogenic layer, blends imperceptibly with the cartilage, so that its innermost boundary cannot be positively established. Chondroblasts lie in the chondrogenic layer immediately adjacent to the cartilage itself and secrete cartilage matrix around themselves.



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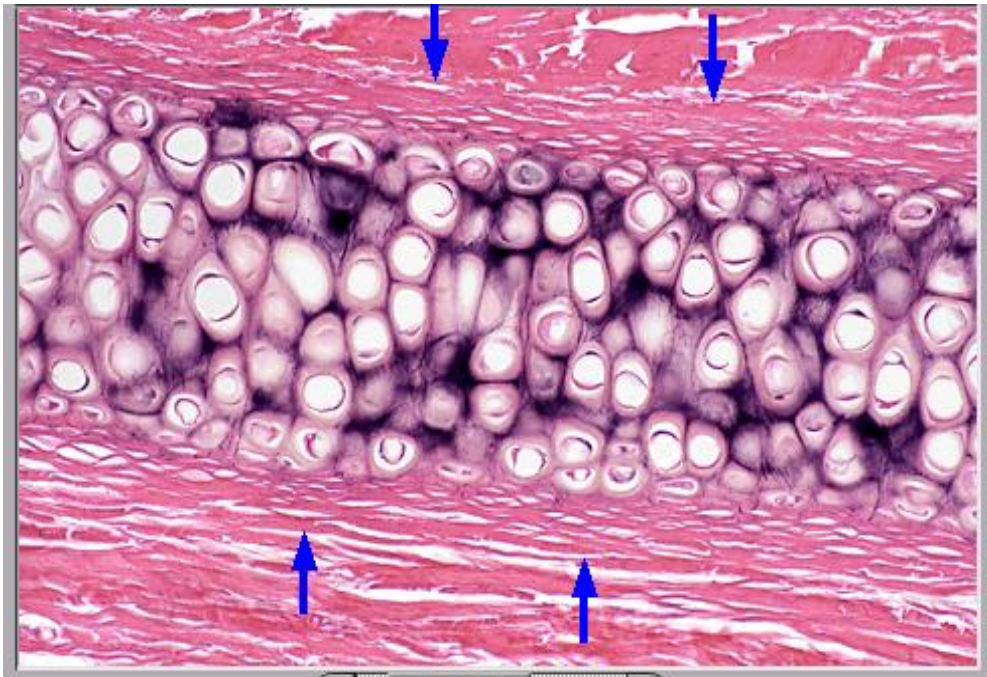
click to identify:

- Chondrocytes
- Elastic fibers
- Perichondrium: > chondrogenic layer
- › Chondroblasts
- Perichondrium: > fibrous layer

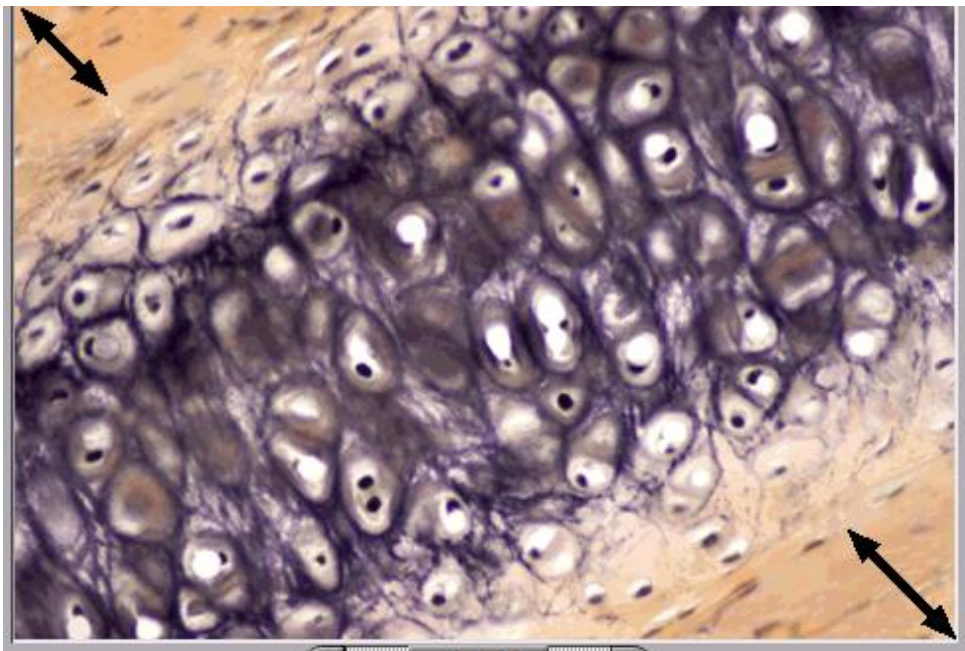


2 of 5

The arrows indicate the boundary of the fibrous portion with the chondrogenic portion of the perichondrium.

click to identify:

- Chondrocytes
- Elastic fibers
- Perichondrium: > chondrogenic layer
- Chondroblasts
- › Perichondrium: > fibrous layer

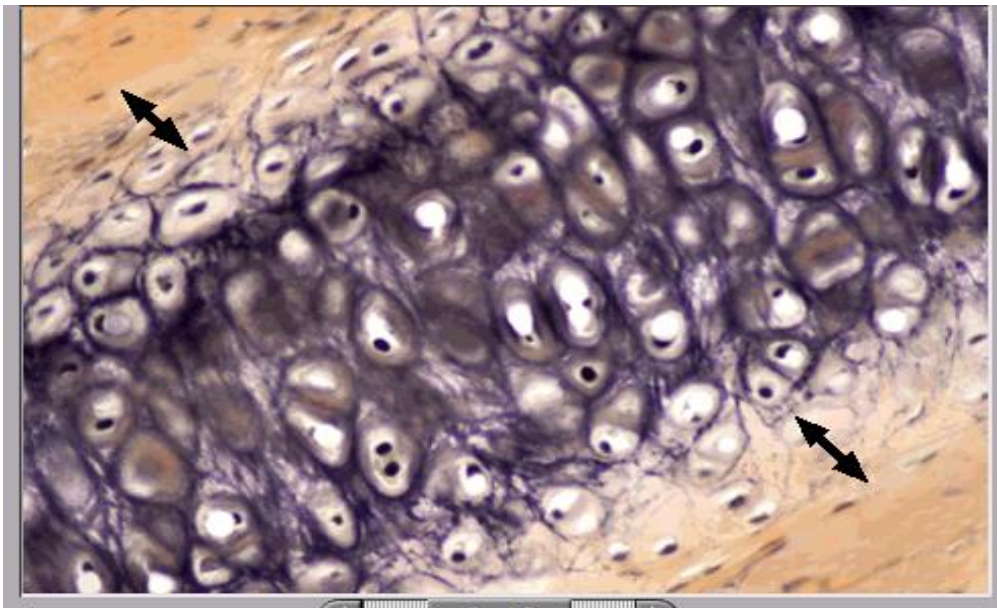


3 of 5

Elastic cartilage -- Elastic cartilage from the pinna of the ear is stained with a dye specific for elastin. Note the abundant chondrocytes, the few isogenous groups and the very obvious, purple-black elastic fibers found in the extracellular matrix. 200x

click to identify:

- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers



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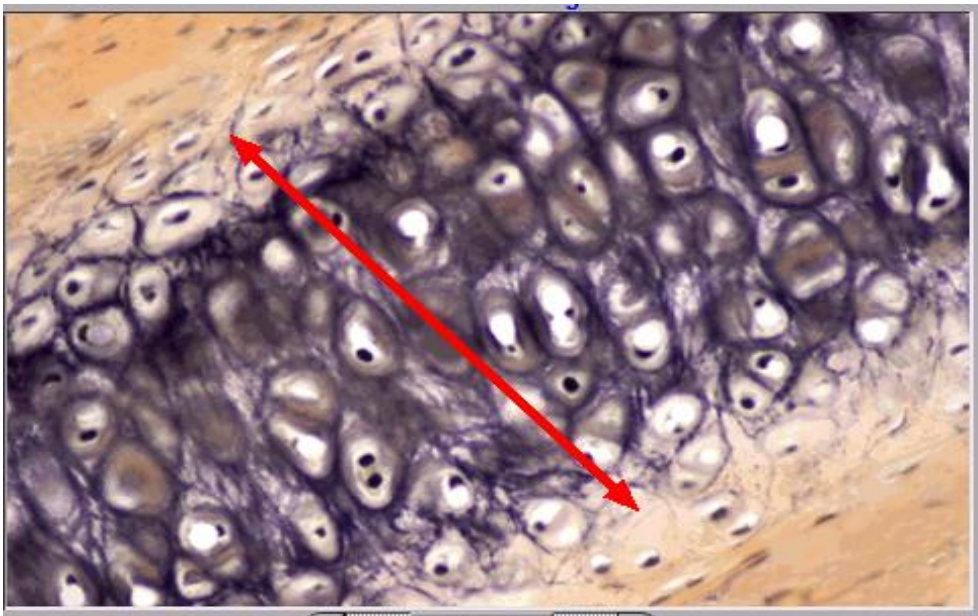

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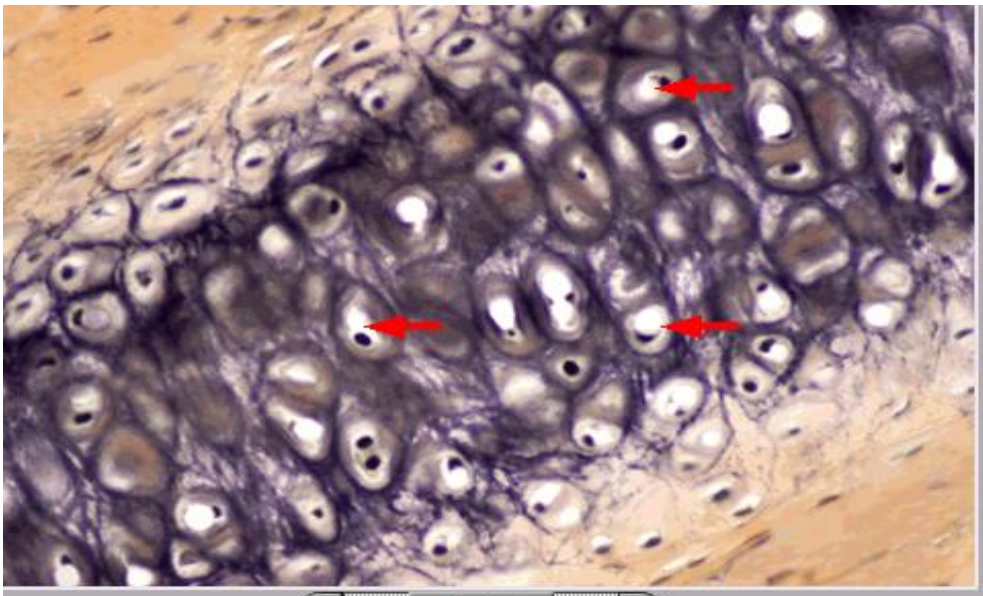

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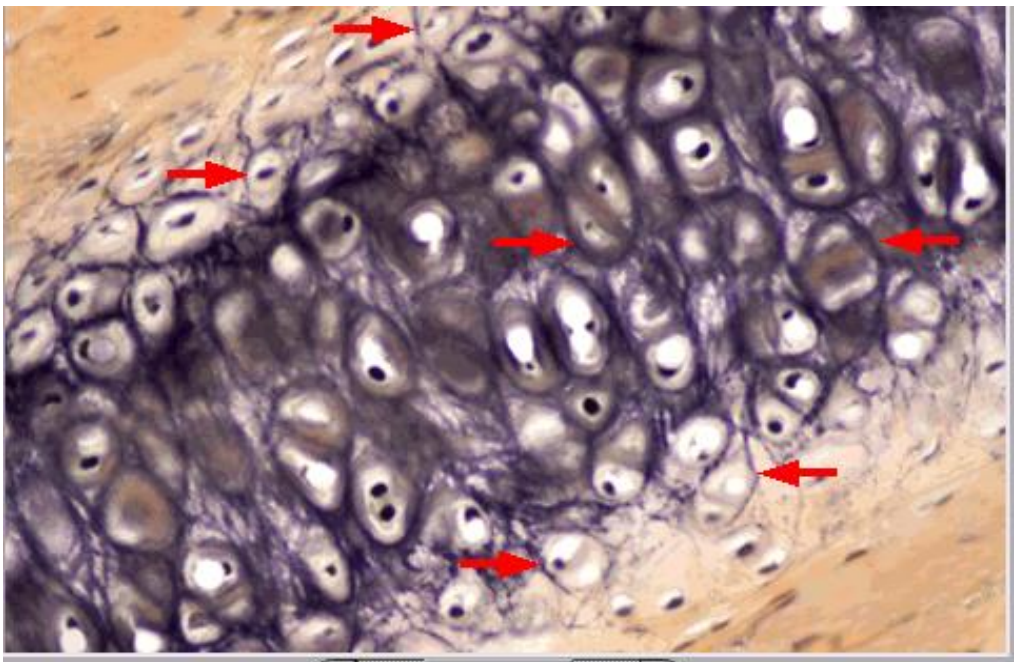

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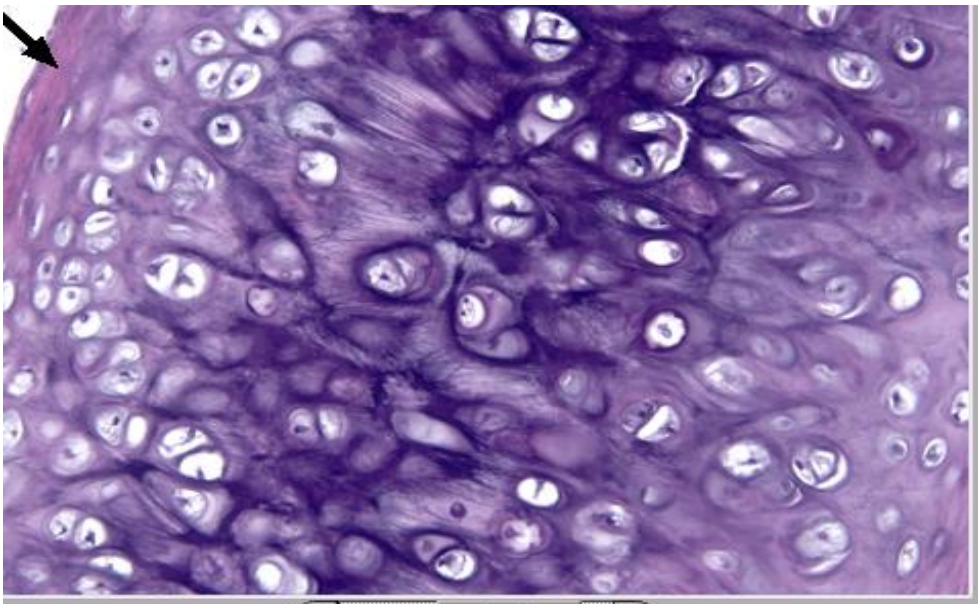
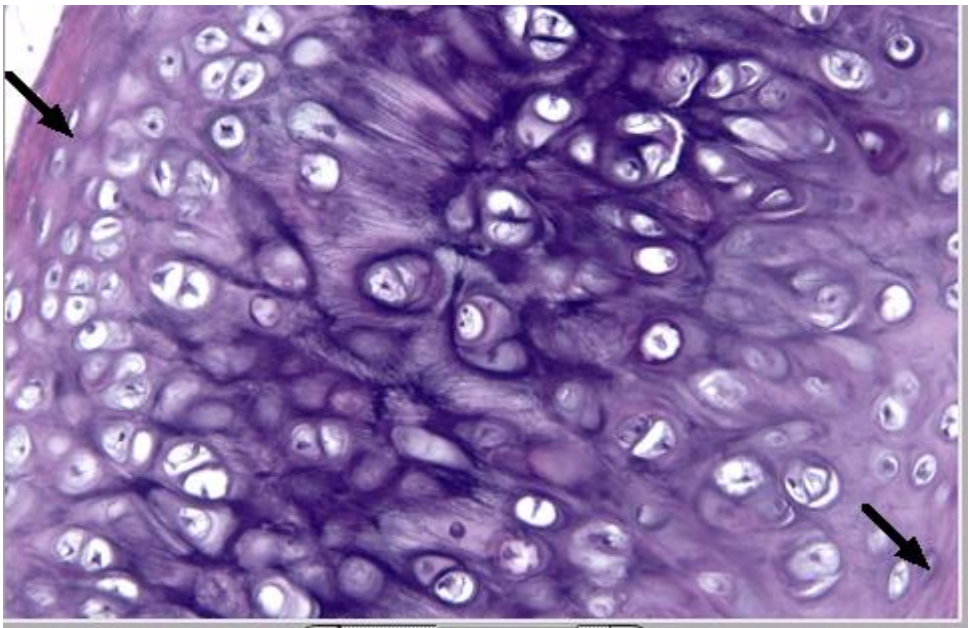


click to identify:

- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers
- Next image

4 of 5

Elastic cartilage -- The qualities that distinguish elastic cartilage are quite evident here: numerous chondrocytes with few isogenous groups, less extracellular matrix than hyaline cartilage and abundant, very obvious elastic fibers. 200x



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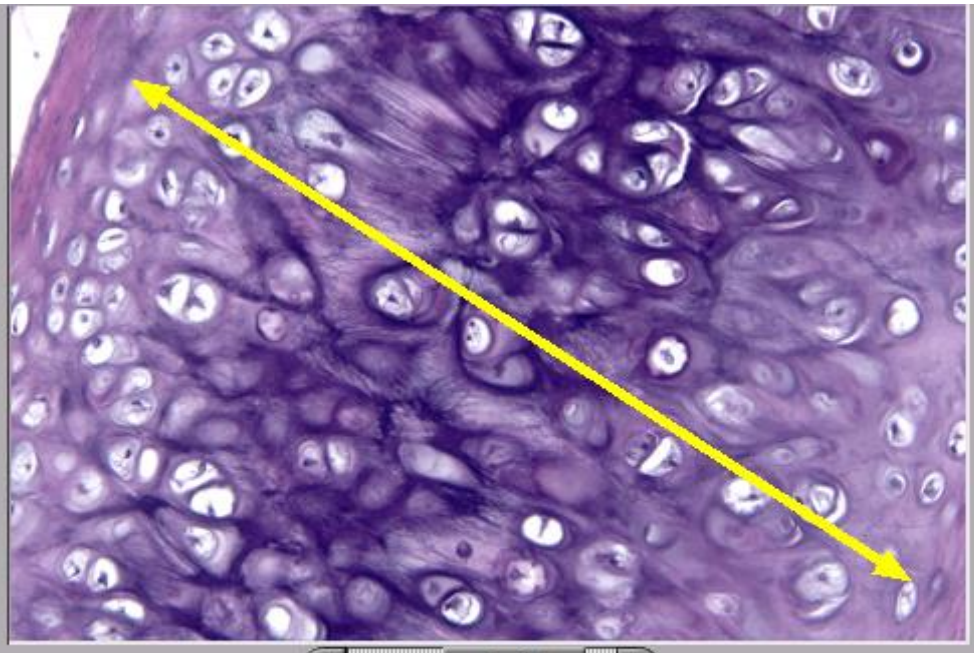
click to identify:

- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers
- Next image



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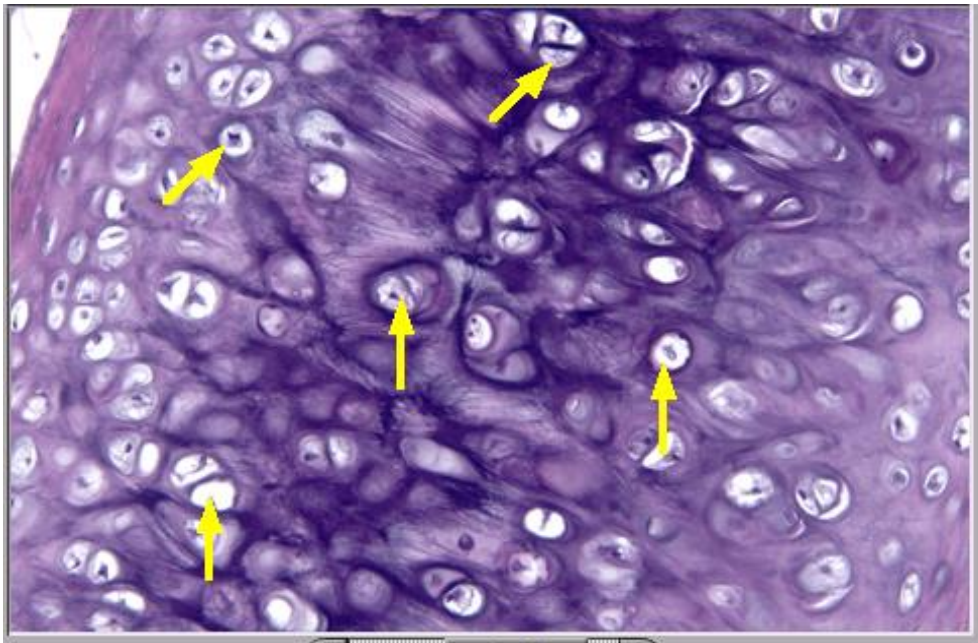
- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers
- Next image



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- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers
- Next image

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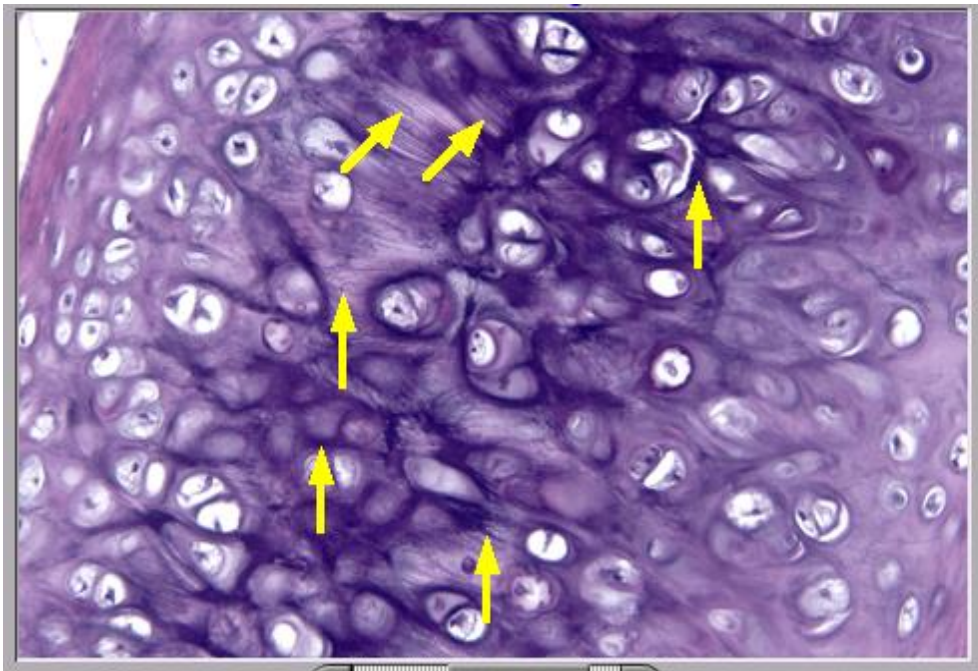

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- Perichondrium: fibrous layer
- Perichondrium: chondrogenic layer
- Elastic cartilage
- Chondrocytes
- Elastic fibers
- Next image

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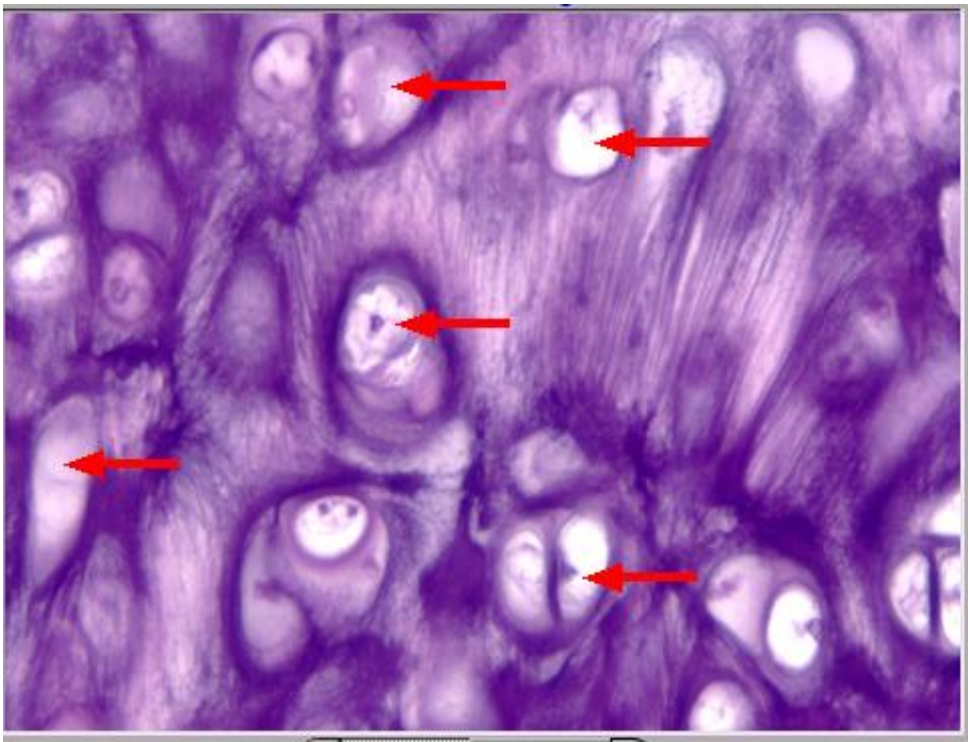
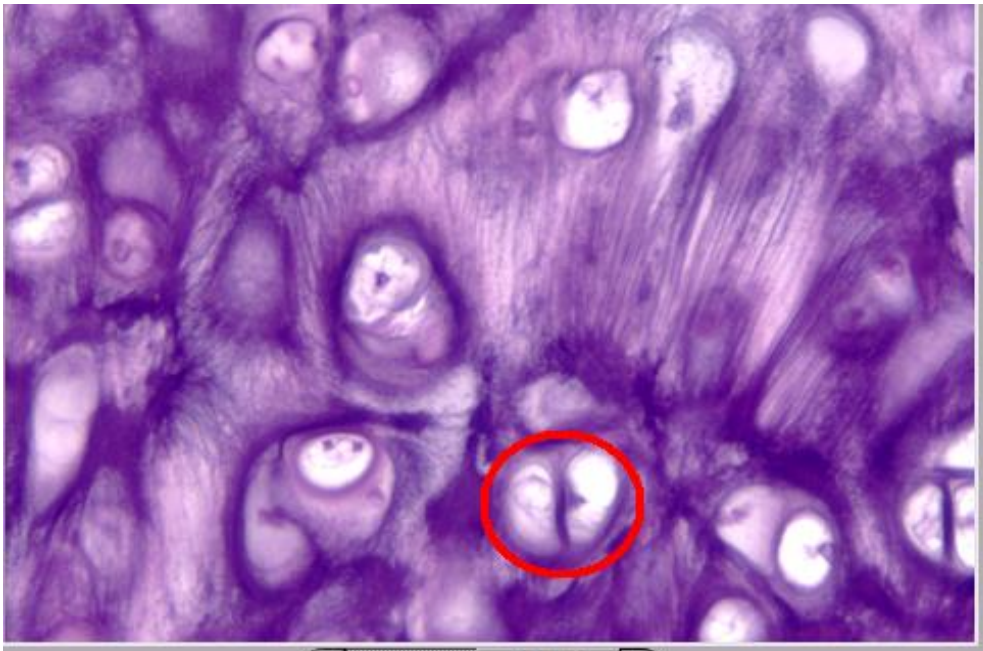


click to identify:

- Chondrocytes
- Isogenous group
- Elastic fibers

5 of 5

Elastic cartilage -- With a special stain, elastic fibers are readily visible in elastic cartilage, helping to differentiate it from hyaline cartilage. 400x



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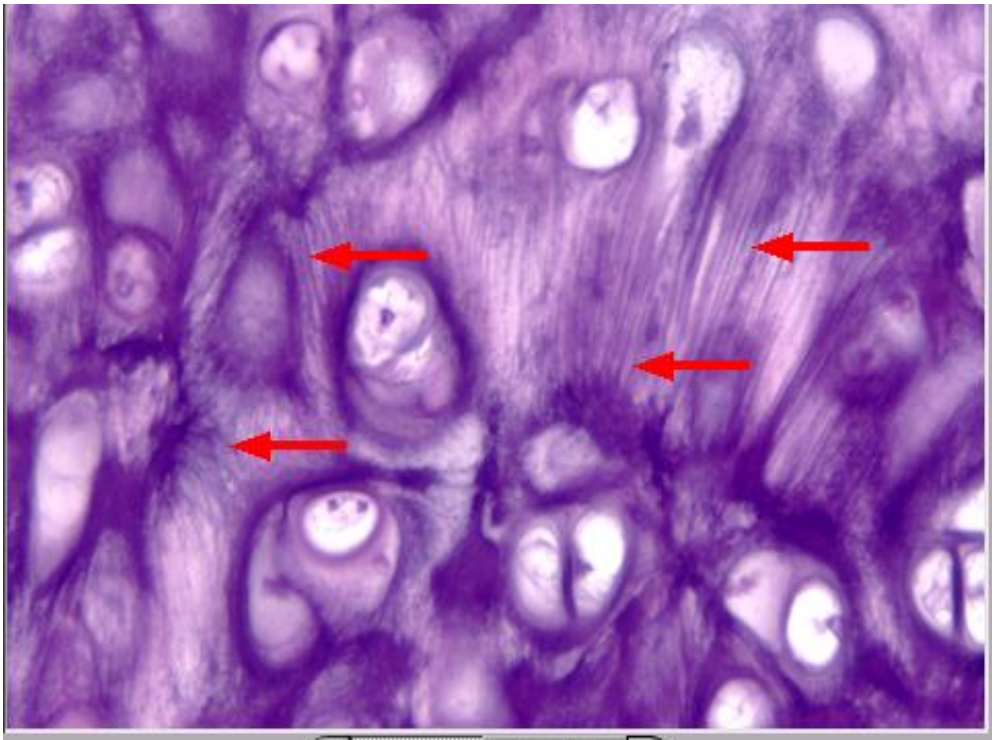

click to identify:

Chondrocytes
Isogenous group
› Elastic fibers

5 of 5

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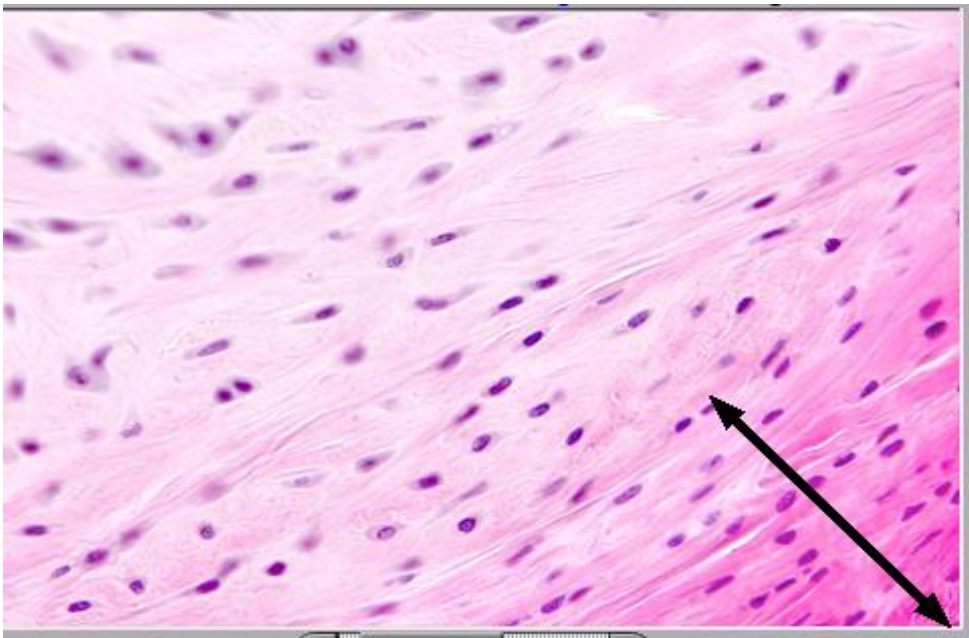
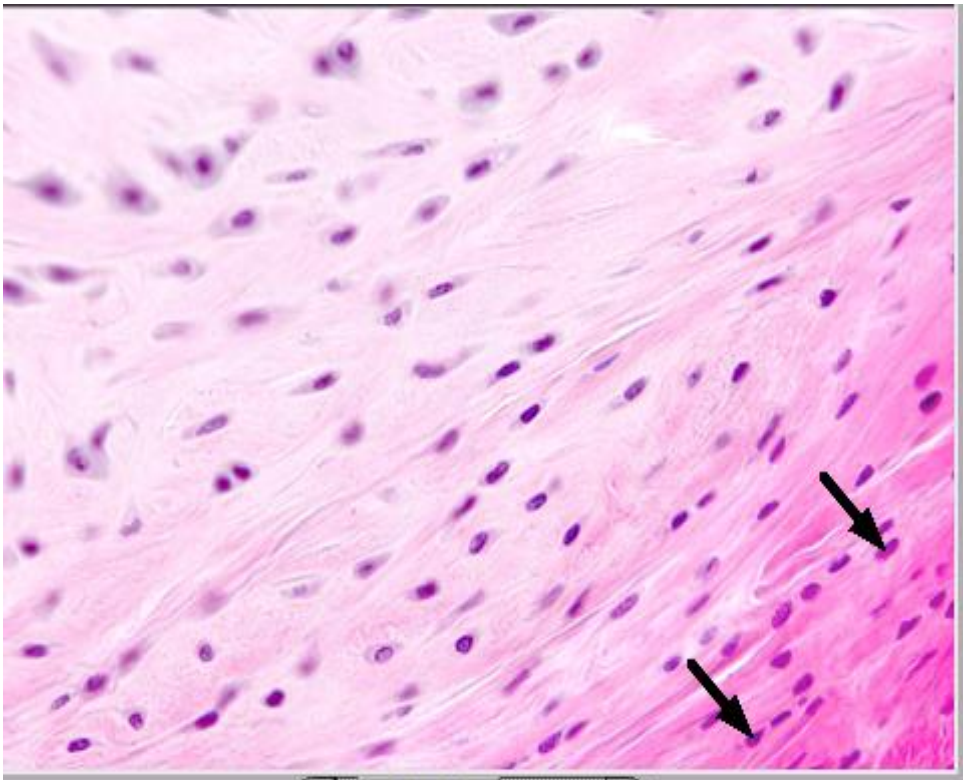


click to identify:

› Dense irregular > connective tissue
Fibroblasts
Fibrocartilage >
Chondrocytes
Collagen fibers

2 of 7

In dense connective tissue, fibroblasts usually possess flattened nuclei (not well demonstated here in actively forming, embryonic tissue) with little cytoplasm. Collagen fiber bundles are obvious in this tissue.



click to identify:

Dense irregular > connective tissue
› Fibroblasts
Fibrocartilage >
Chondrocytes
Collagen fibers

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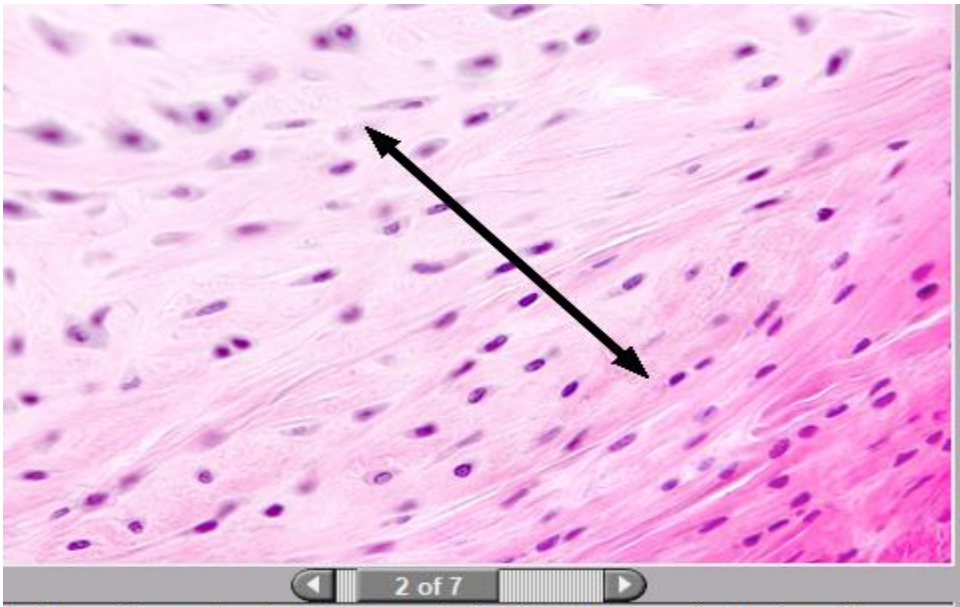
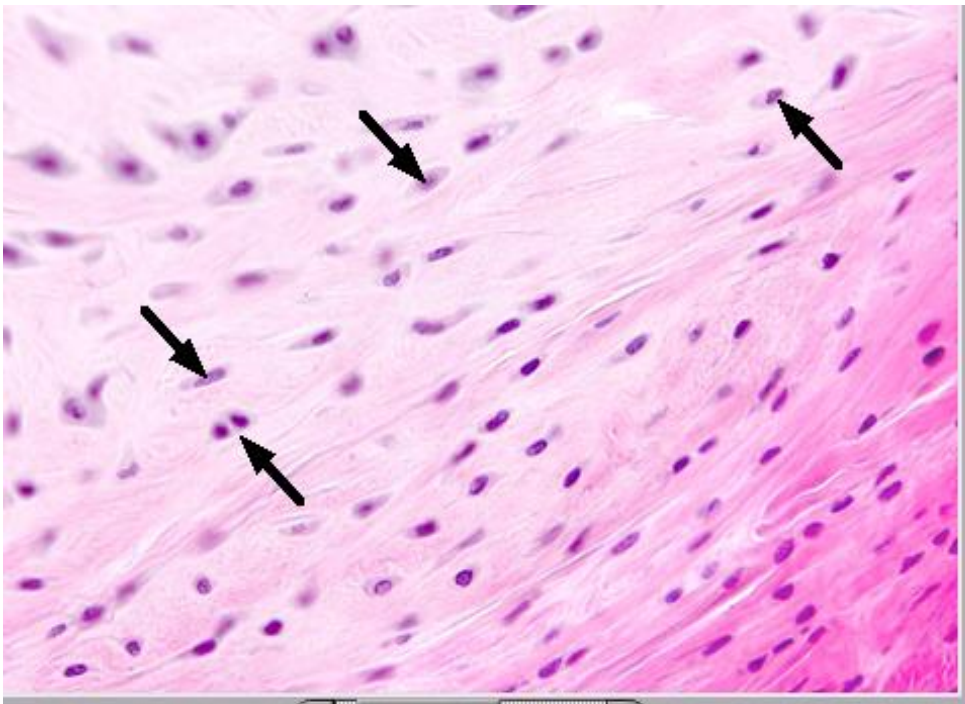


click to identify:

Dense irregular > connective tissue
Fibroblasts
› Fibrocartilage >
Chondrocytes
Collagen fibers

2 of 7

In fibrocartilage, chondrocytes are protected from compression by the rubbery cartilage ground substance. Therefore, these cells display rounder nuclei and visible, basophilic cytoplasm. Collagen fiber bundles are obvious in this tissue.



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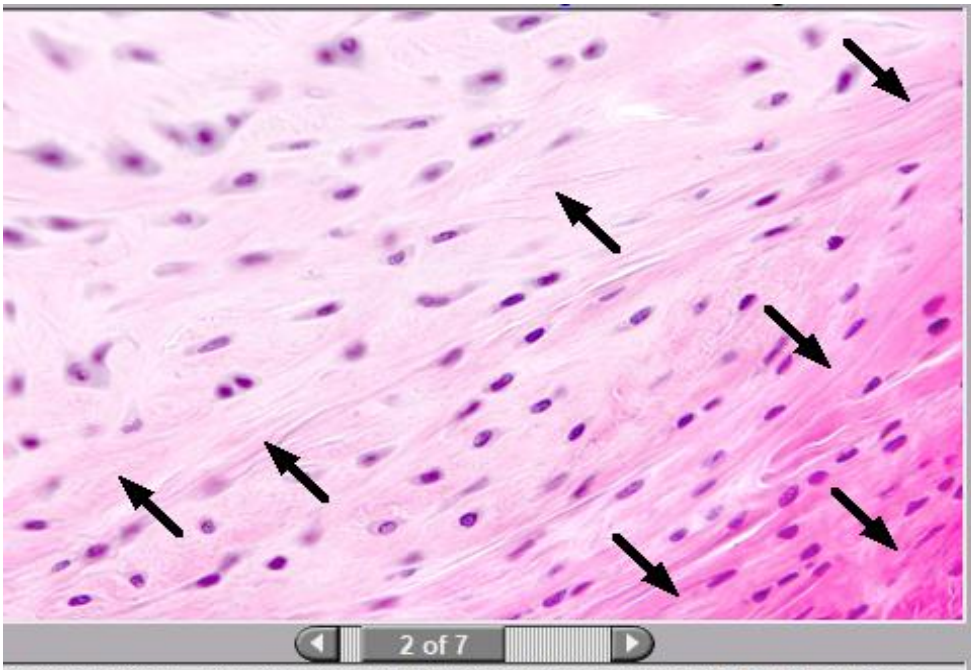

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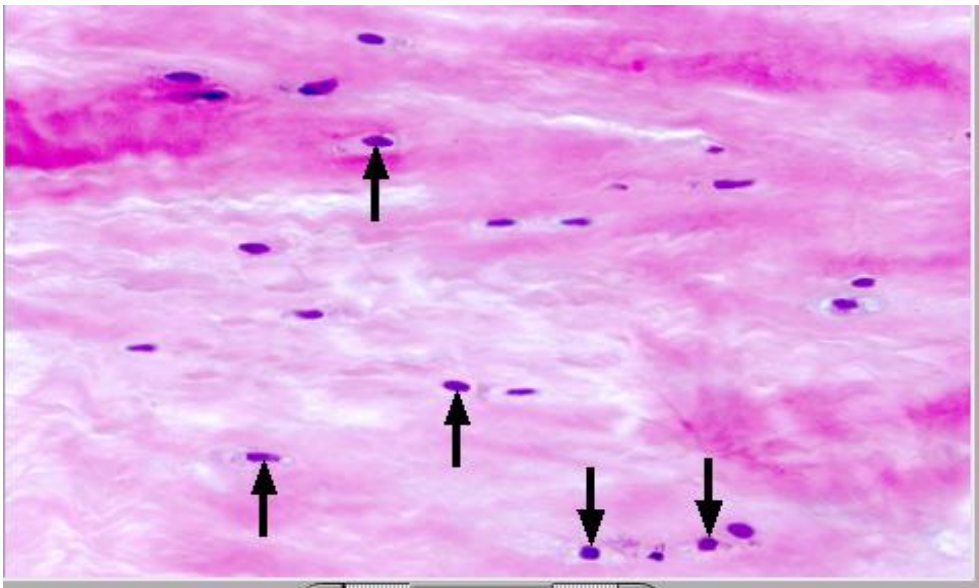
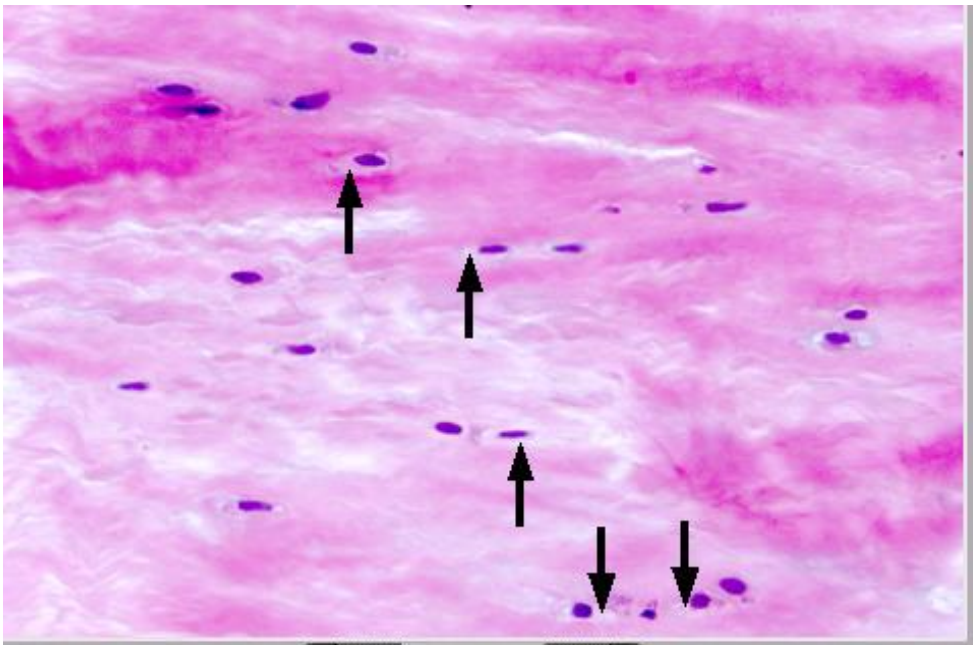


4 of 7

Fibrocartilage -- Fibrocartilage whose fibers are irregularly arranged is difficult to differentiate from dense irregular connective tissue. Rounded chondrocytes, frequently with visible cytoplasm and lacunae, differentiate fibrocartilage from connective tissue proper. Fibroblasts are distinguished by their flattened, heterochromatic nuclei and lack of visible cytoplasm and lacunae. 400x

click to identify:

- Chondrocytes
- Cytoplasm
- Collagen bundles
- Fibroblasts



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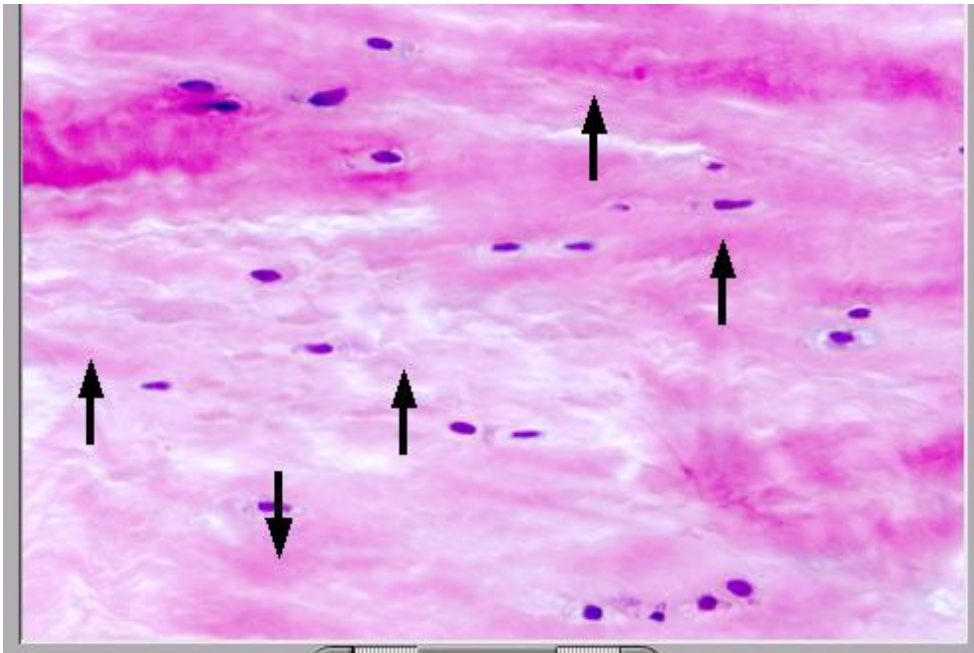

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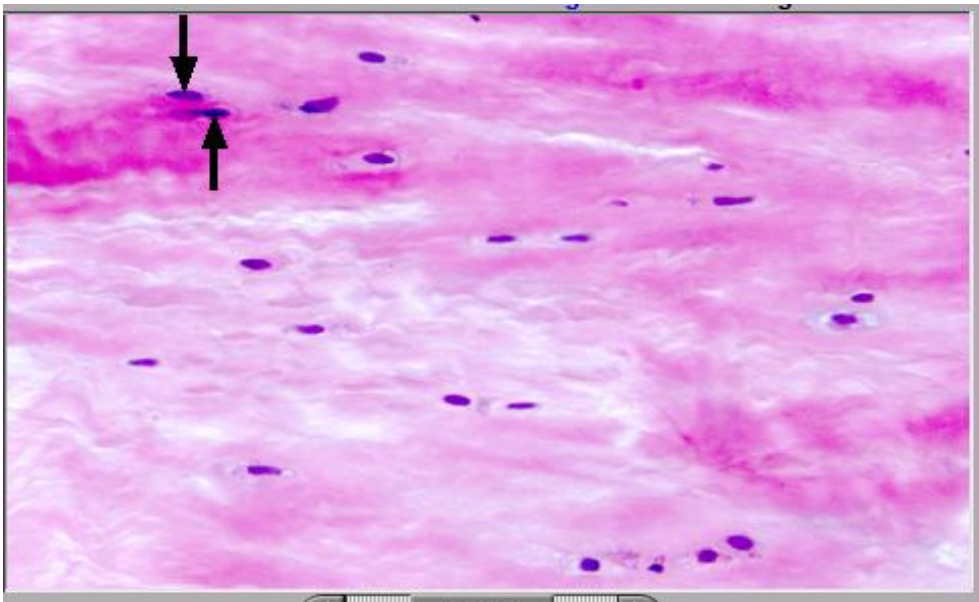

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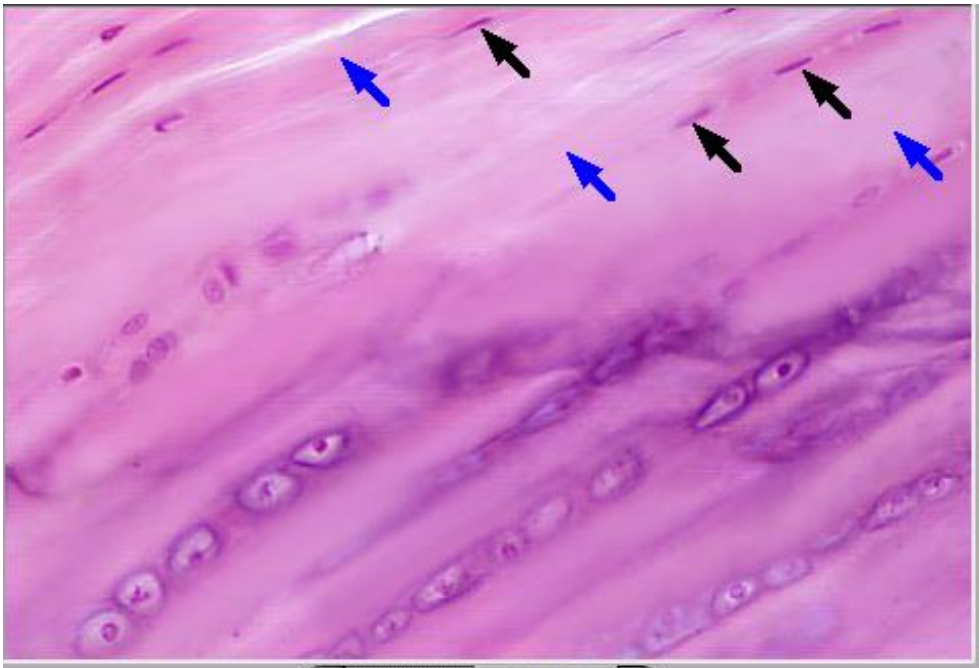
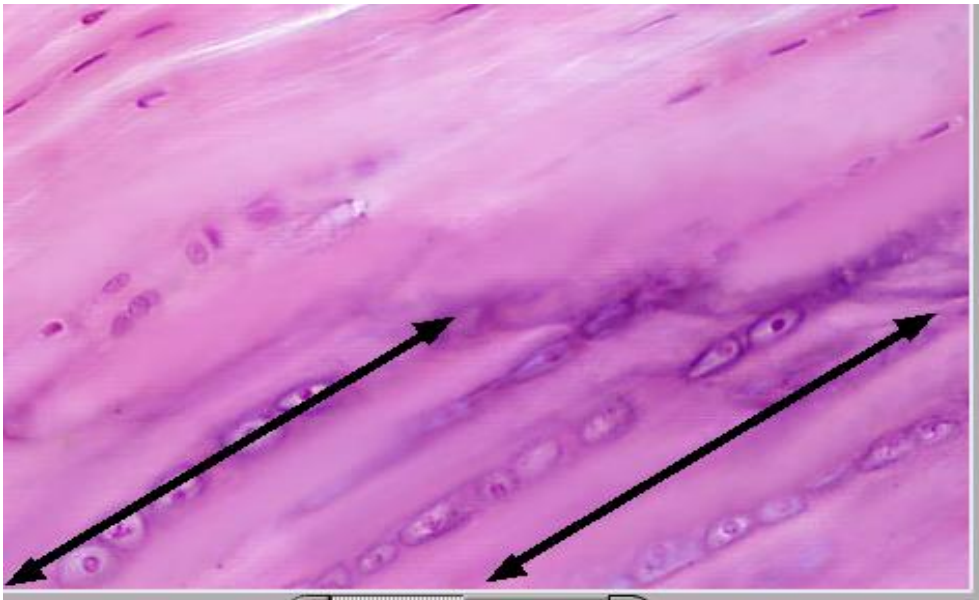


7 of 7

In dense regular connective tissue, fibroblasts are inactive with flattened, heterochromatic nuclei (black arrows). The extracellular matrix is represented primarily by the regularly arranged collagen bundles (blue arrows), causing this connective tissue to stain pink with eosin. Little ground substance is present.

click to identify:

- Dense regular > connective tissue
- Fibrocartilage >
  - Collagen fibers
  - Chondrocytes
  - Ground substance
- Transitional area >



7 of 7

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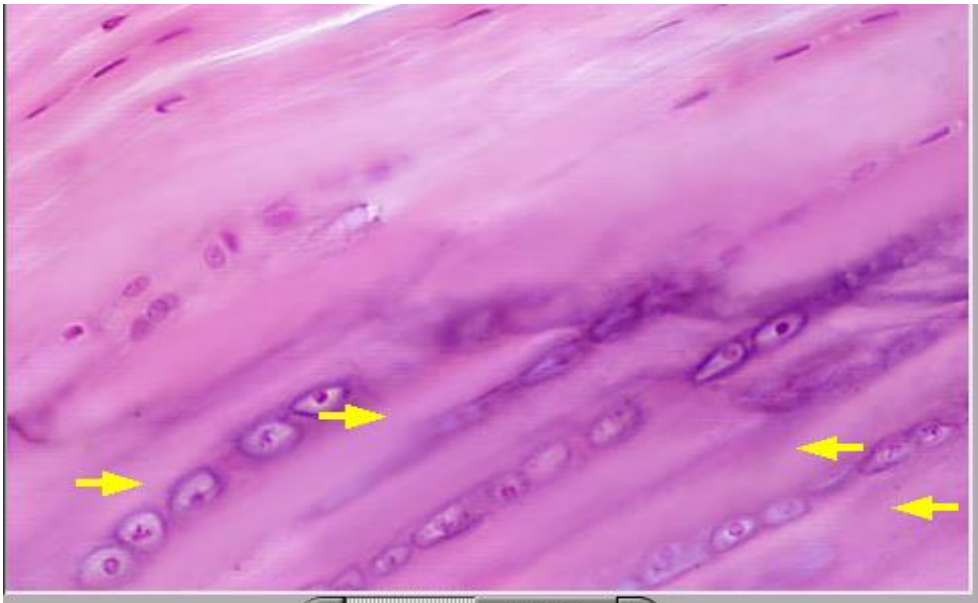
click to identify:

- Dense regular > connective tissue
- Fibrocartilage >
  - Collagen fibers
  - Chondrocytes
  - Ground substance
- Transitional area >

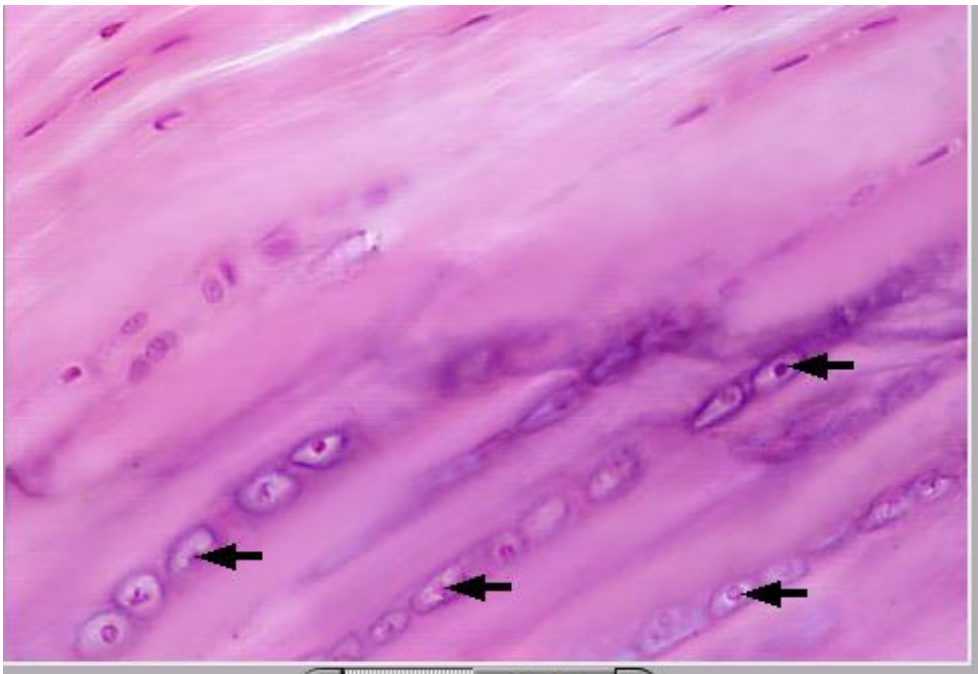


7 of 7

Collagen fibers continue uninterrupted into fibrocartilage. However, the cells (chondrocytes) in their lacunae are now spherical, protected by the surrounding firm-rubber ground substance. The increased abundance of this ground substance (as compared to tendon) produces the bluer color of fibrocartilage.

click to identify:

- Dense regular > connective tissue
- Fibrocartilage >
  - Collagen fibers
  - Chondrocytes
  - Ground substance
- Transitional area >



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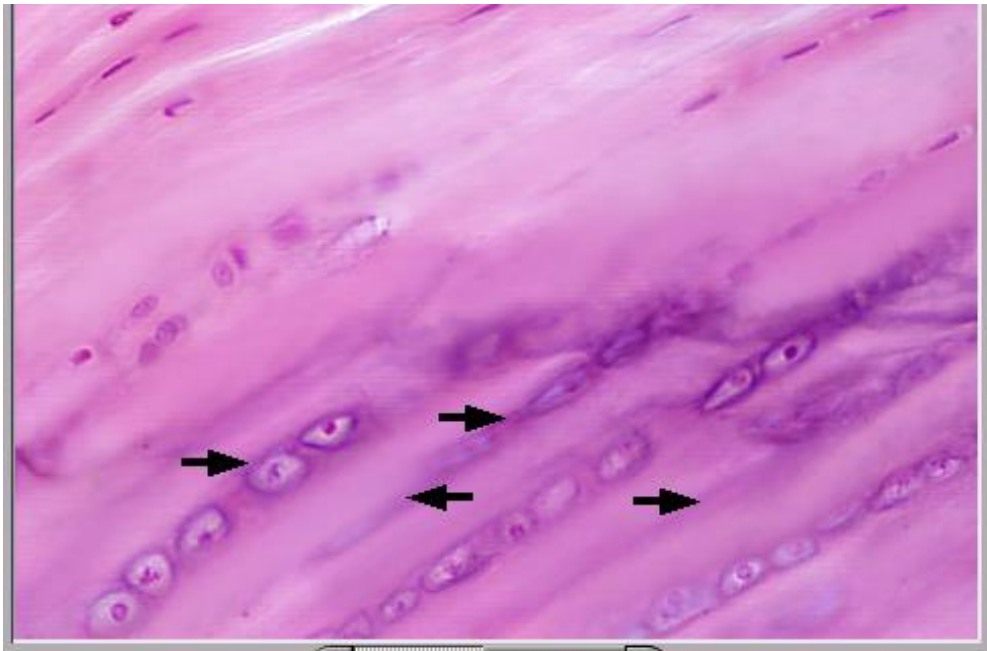
- Dense regular > connective tissue
- Fibrocartilage >
  - Collagen fibers
  - Chondrocytes
  - Ground substance
- Transitional area >



click to identify:

Dense regular > connective tissue
Fibrocartilage >
Collagen fibers
Chondrocytes
› Ground substance
Transitional area >

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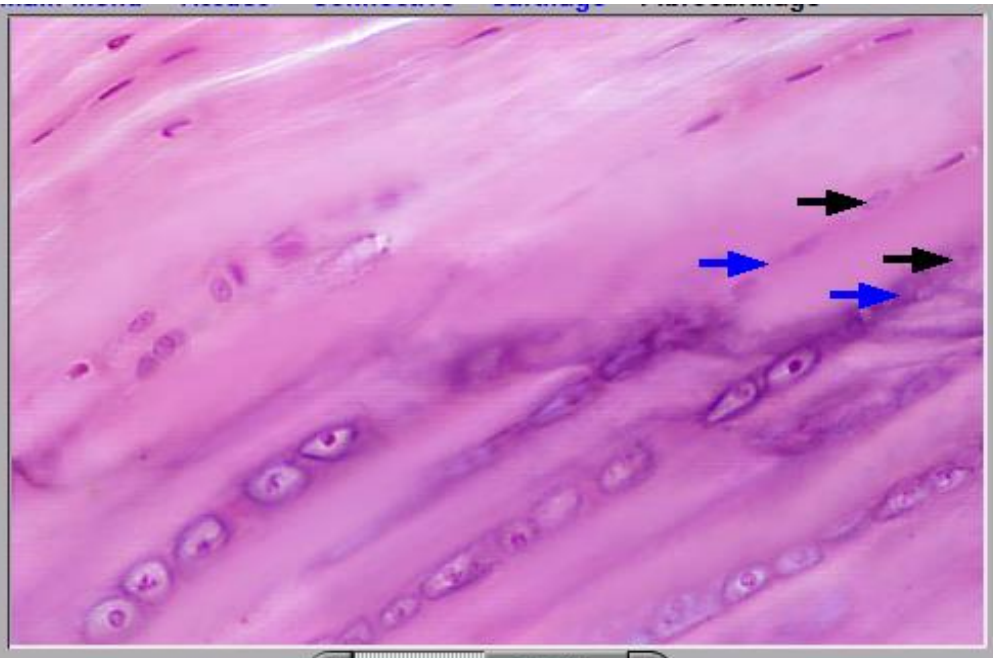
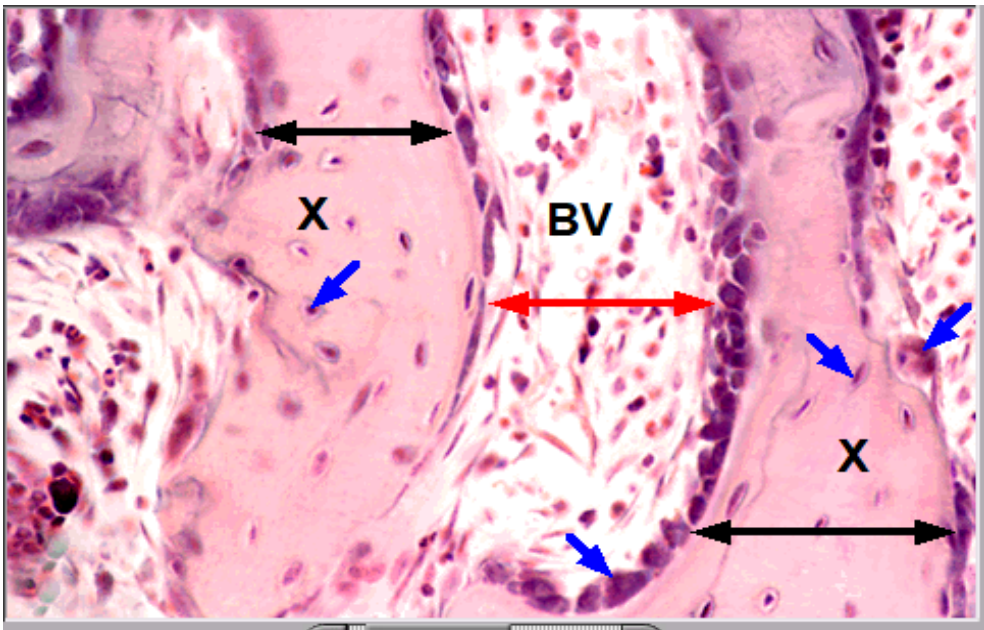


click to identify:

Dense regular > connective tissu
Fibrocartilage >
Collagen fibers
Chondrocytes
Ground substance
› Transitional area

7 of 7

A transition area exists between these two tissues, where the cells (black arrows) are beginning to round up and the ground substance (blue arrows) becomes more abundant than in tendon.

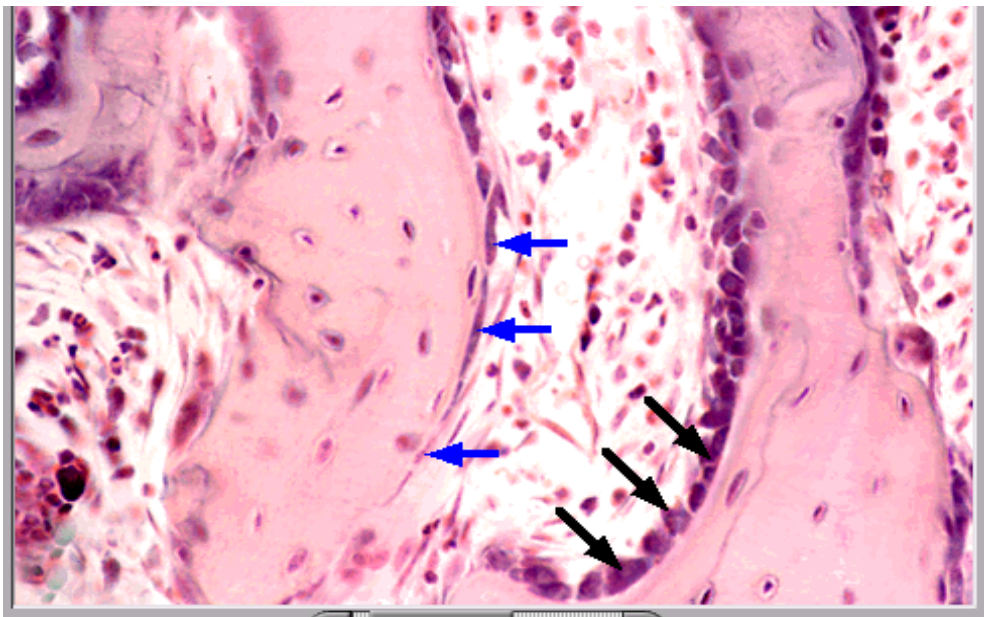


3 of 15

This decalcified image shows several spicules (slender spikes) of pink-staining bone (black arrows) surrounded by loose connective tissue (red arrow). Bone cells, consisting of osteoblasts, osteocytes and osteoclasts (blue arrows), and extracellular matrix (X) can be identified. A blood vessel (BV) is present in the loose connective tissue adjacent to the bone.

click to identify:

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular > matrix

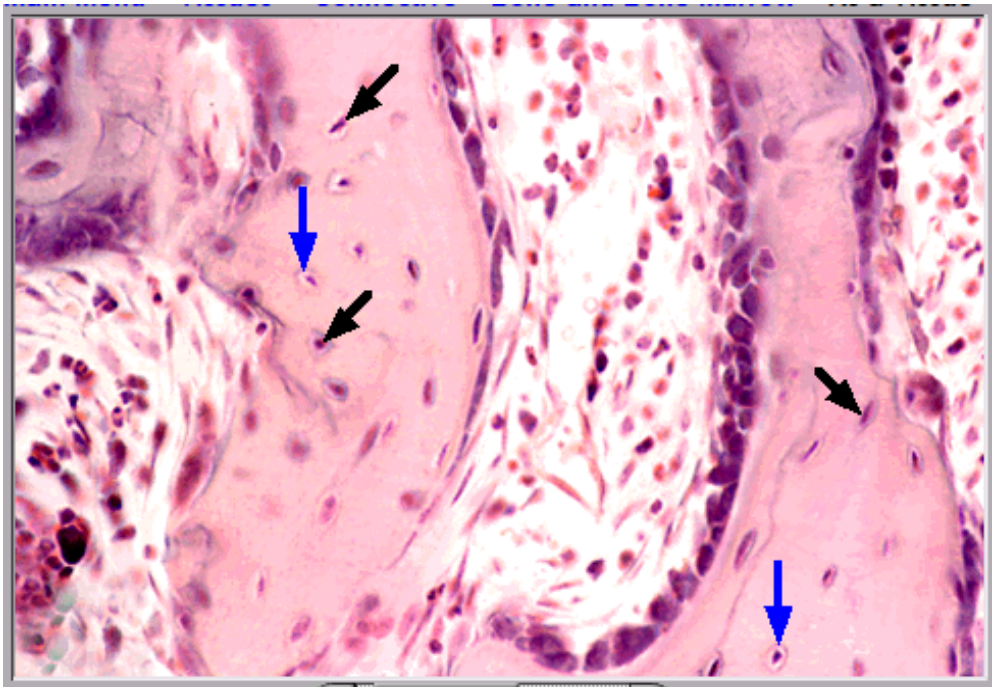


3 of 15

Osteoblasts lie on the surface of bone and produce its extracellular matrix. If these cells are actively producing ground substance and collagen fibers, they are large, plump cells (black arrows) filled with the organelles necessary for protein production. If the osteoblasts are inactive (blue arrows), the cells and nuclei are flattened. Osteoblasts are located in the endosteum and periosteum.

click to identify:

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular > matrix

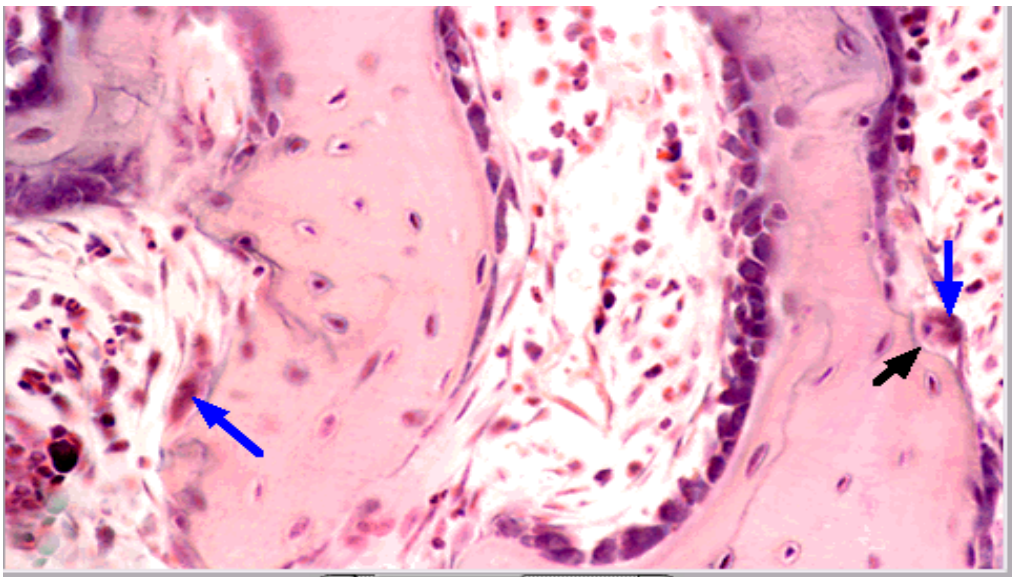


3 of 15

Osteocytes (black arrows) are osteoblasts that have surrounded themselves with matrix and, therefore, lie within (rather than on) bone. Although not seen here, numerous processes radiate out from each cell body, communicating with other osteocytes and with surface osteoblasts. Osteocytes lie within spaces called lacunae, seen here as a halo (blue arrows) surrounding each cell body.

click to identify:

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular matrix

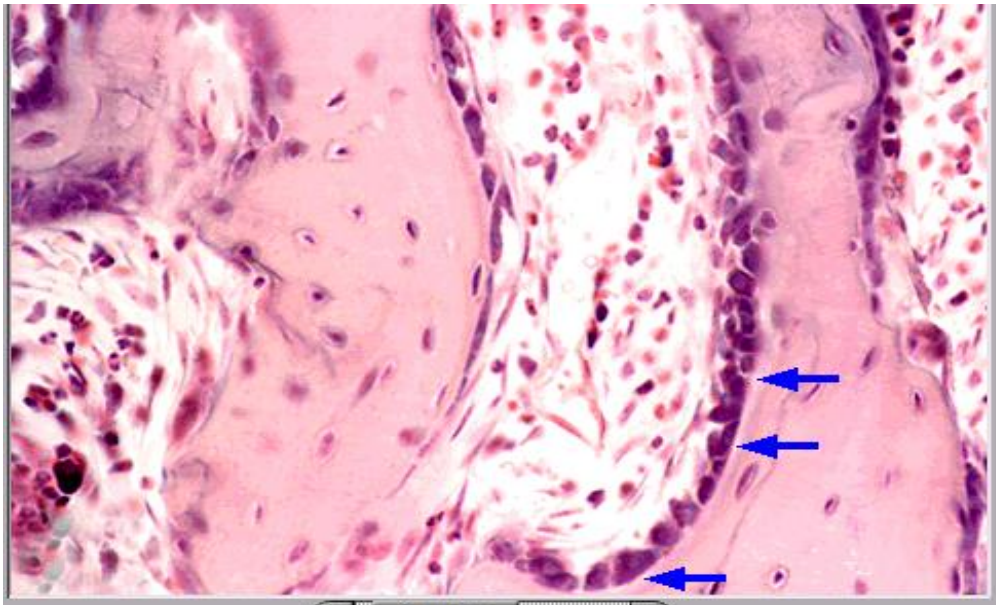


3 of 15

Osteoclasts (blue arrows), the third type of bone cell, lie on the surface of bone in the endosteum and periosteum. These cells resorb bone, forming tiny depressions called Howship's lacunae (black arrow) as they do so. Osteoclasts are large, multinucleated cells containing many lysosomes; numerous infoldings face the bone to increase surface area during bone resorption.

click to identify

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular matrix

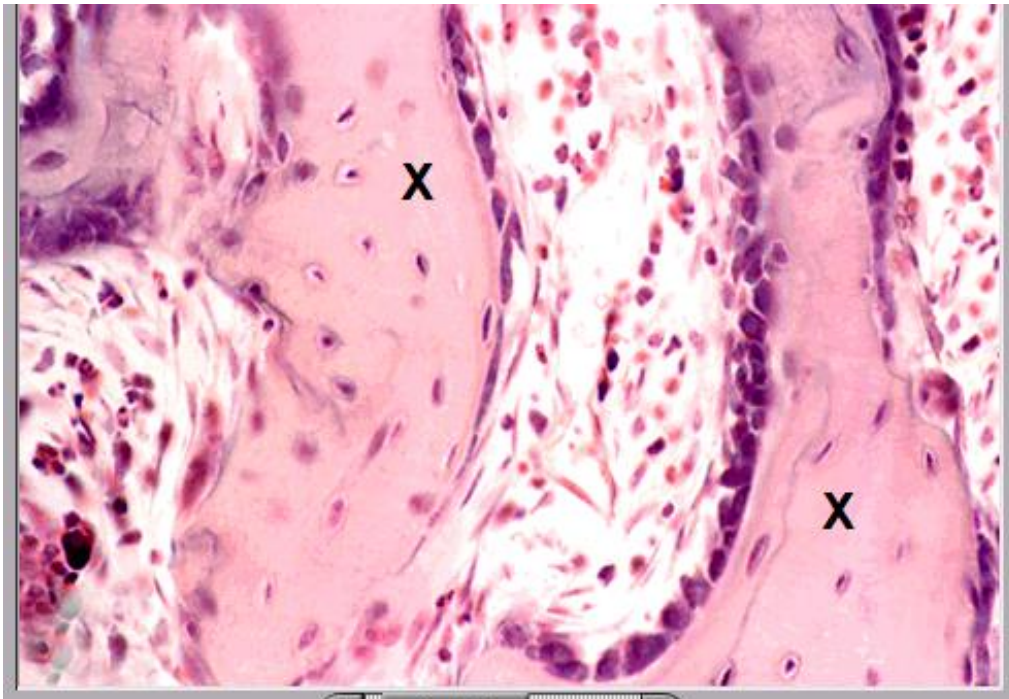


3 of 15

Formation of the extracellular matrix of bone begins with deposition of the organic portion, osteoid (arrows), by active osteoblasts. Osteoid, composed of ground substance and collagen fibers, appears as a pale band lying on the bone surface beneath the active osteoblasts.

click to identify:

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular > matrix

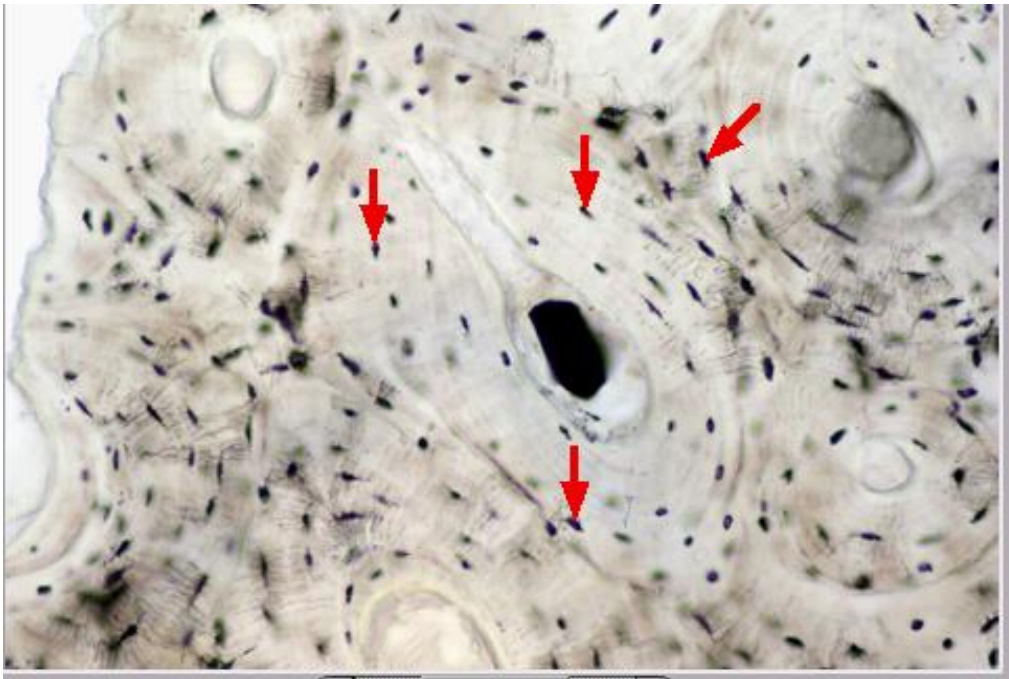


3 of 15

After osteoid is formed, it becomes mineralized by an inorganic matrix of calcium phosphate. The abundance of collagen and calcium and the paucity of ground substance produces an eosinophilic, extracellular matrix.

click to identify:

- Overview >
- Osteoblasts >
- Osteocytes >
- Osteoclasts >
- Organic matrix >
- Extracellular > matrix

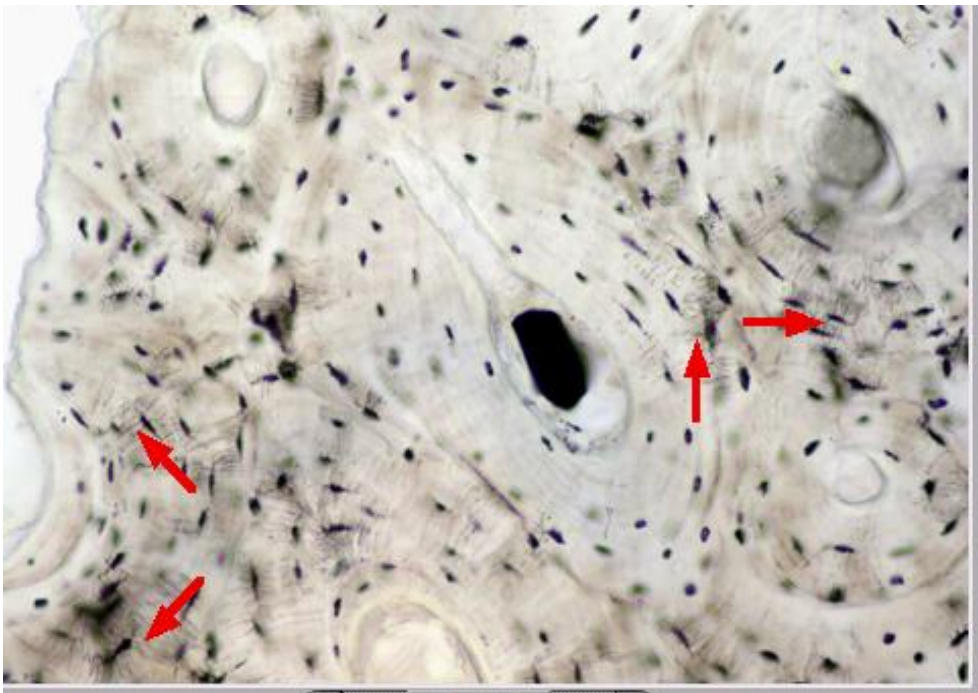


8 of 15

Osteocyte lacunae, where osteocyte cell bodies were located, appear as blackened slits in the bone.

click to identify

- Osteocyte > lacunae
- Canaliculi > Extracellular > matrix



8 of 15

Canaliculi, where osteocyte processes were located in living tissue, radiate from the lacunae toward adjacent osteocytes or osteoblasts.

click to identify:

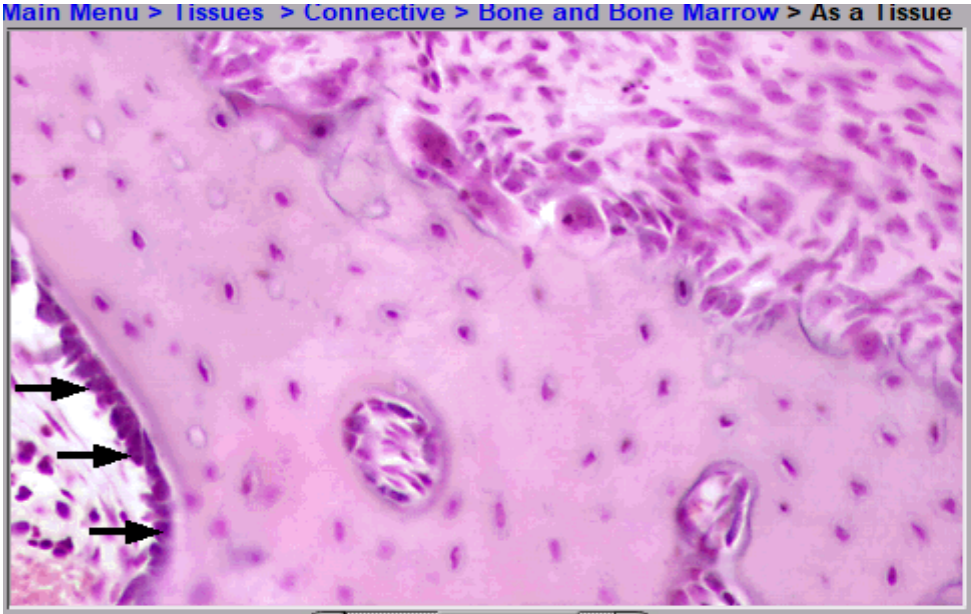
- Osteocyte > lacunae
- Canaliculi > Extracellular > matrix

8 of 15

The extracellular, inorganic matrix (X) displays the layered appearance of the bone. In this image most of the lamellae are concentrically arranged around a central space. These concentric lamellae constitute an osteon, or Haversian system, whose central space is an Haversian canal (Y).

click to identify:

- Osteocyte > lacunae
- Canaliculi >
- > Extracellular > matrix



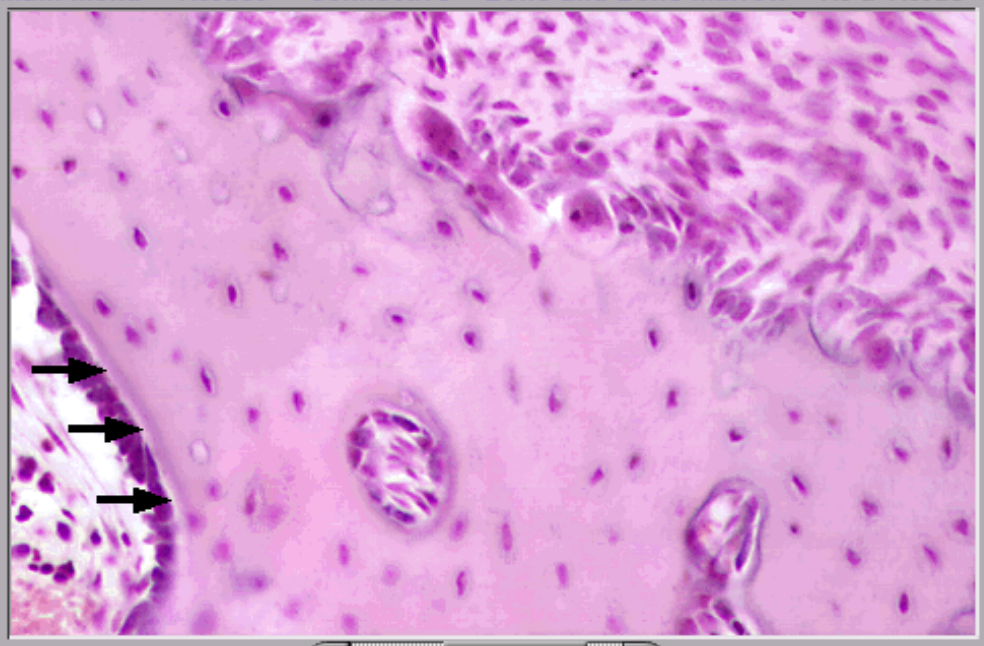
11 of 15

Bone the tissue -- At higher magnification the matrix of this developing woven bone is slightly purple, indicating its relatively high content of ground substance and lower content of fibers and hydroxyapatite; no lamellae are visible. Osteocytes are in a disorganized array and lie in rounded lacunae. 400x

click to identify:

- Woven bone
- > Active osteoblasts
- Osteoid
- Inactive osteoblasts
- Osteocytes
- Osteoclasts

Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



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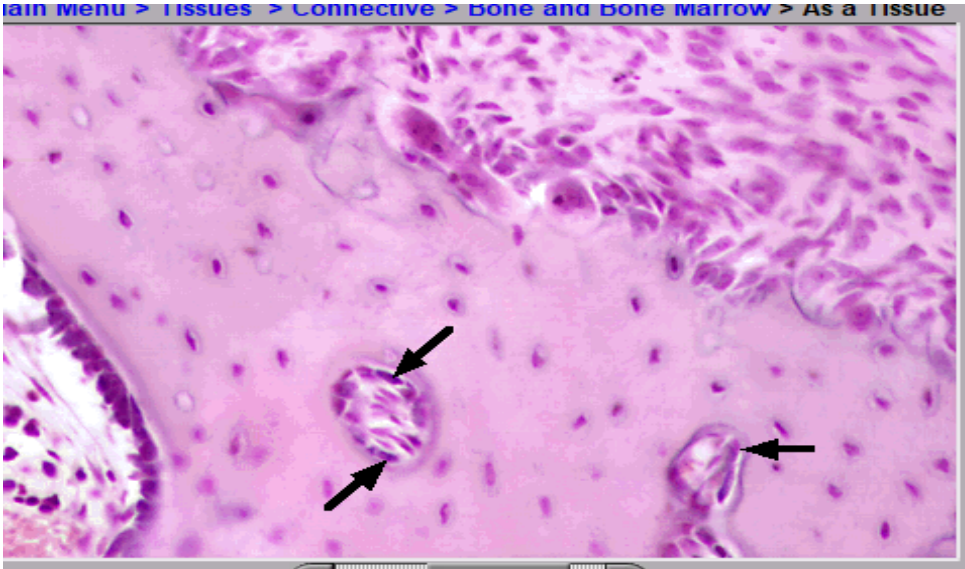

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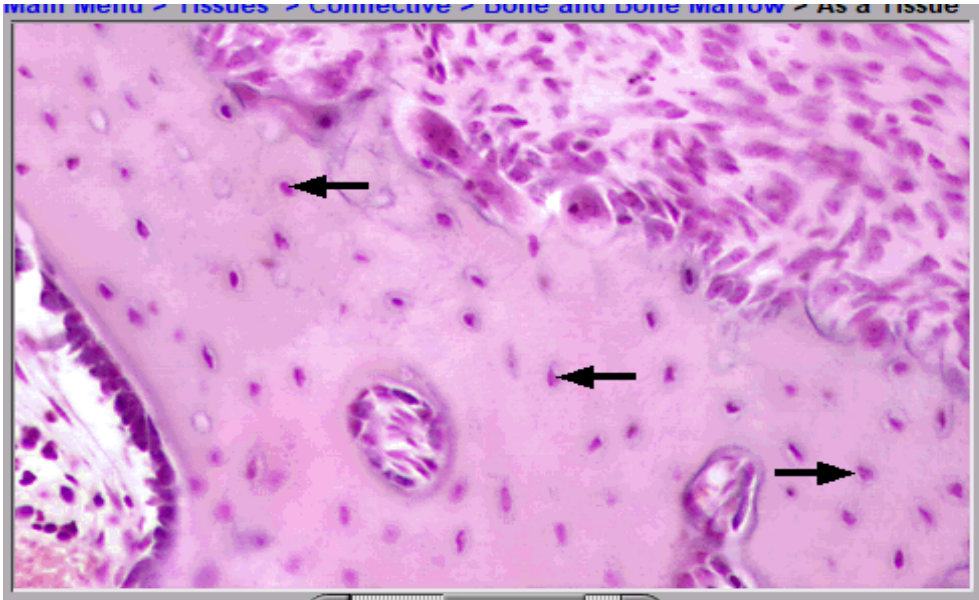

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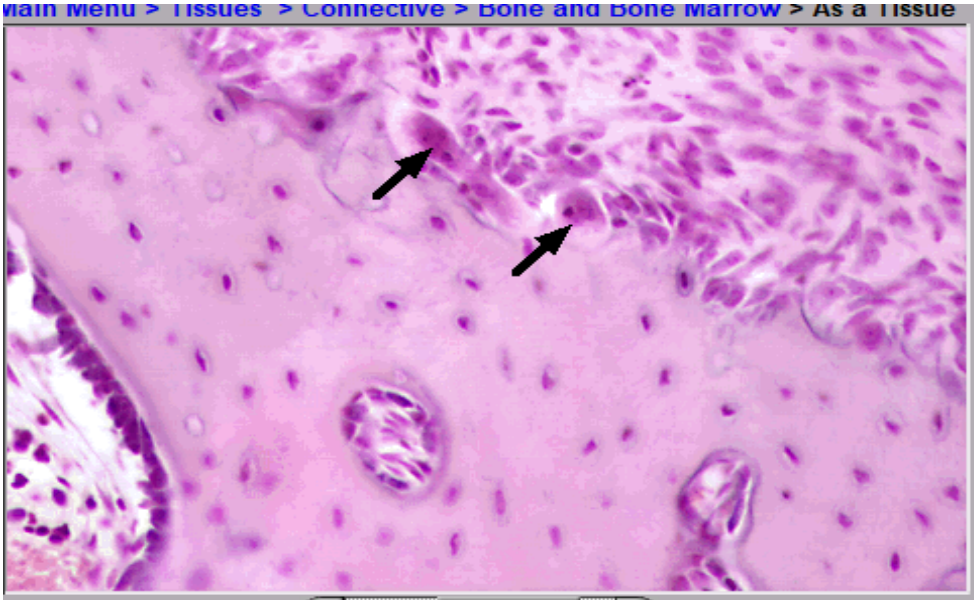
Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



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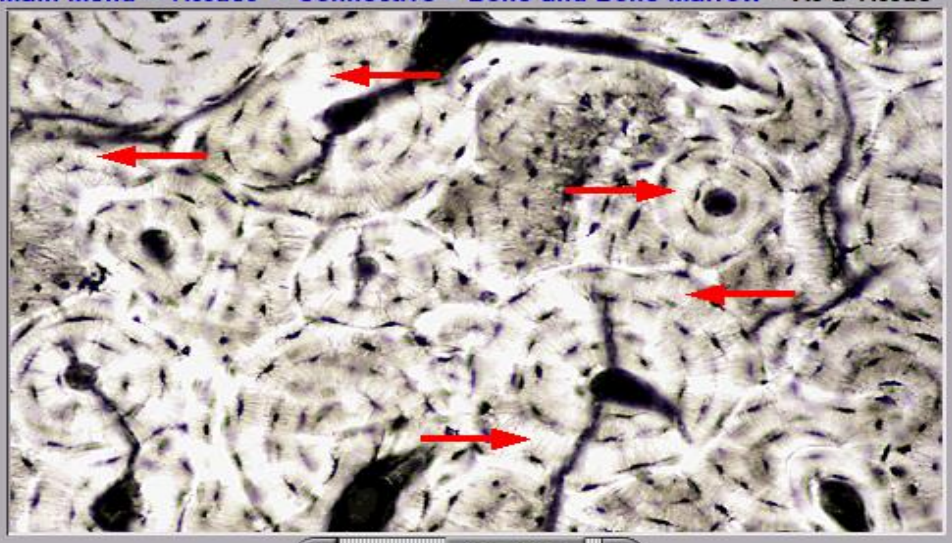
- Active osteoblasts
- Osteoid
- Inactive osteoblasts
- Osteocytes
- Osteoclasts

Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



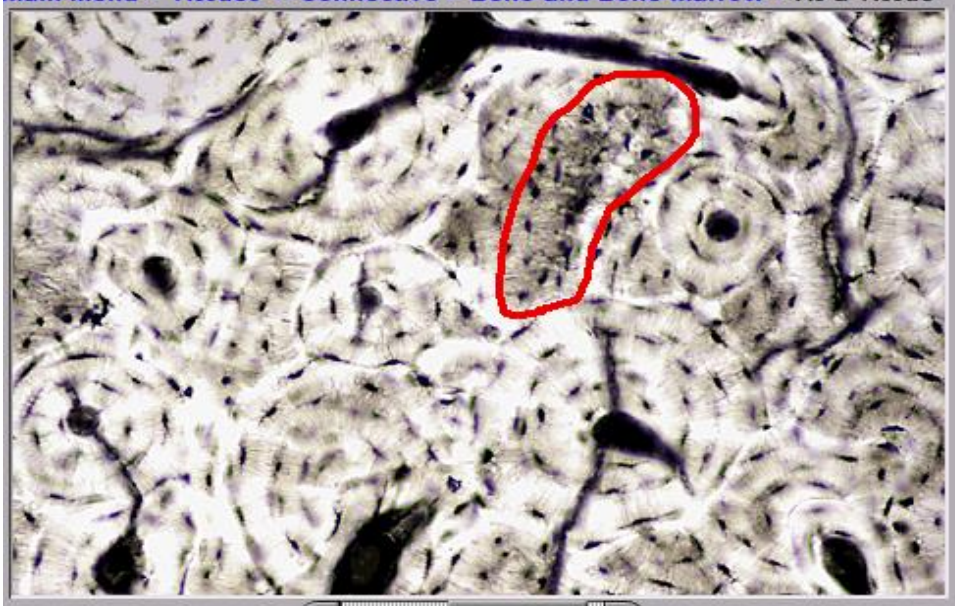
13 of 15

Bone the tissue -- This ground bone preparation shows primarily lamellar, or adult, bone arranged in concentric lamellae. Osteocyte lacunae are flattened and oriented between the lamellae. A small region of woven bone is also visible. 200x

click to identify:

- Lamellar bone
- Osteocyte lacunae
- Woven bone
- Osteons >
- Haversian canals
- Volkmann's canals

Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



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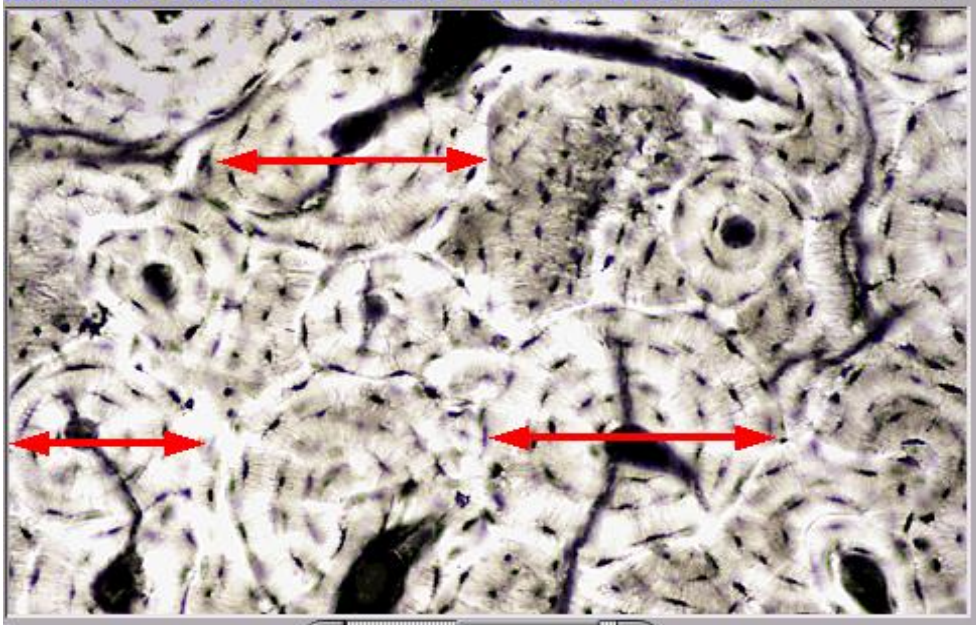
Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



13 of 15

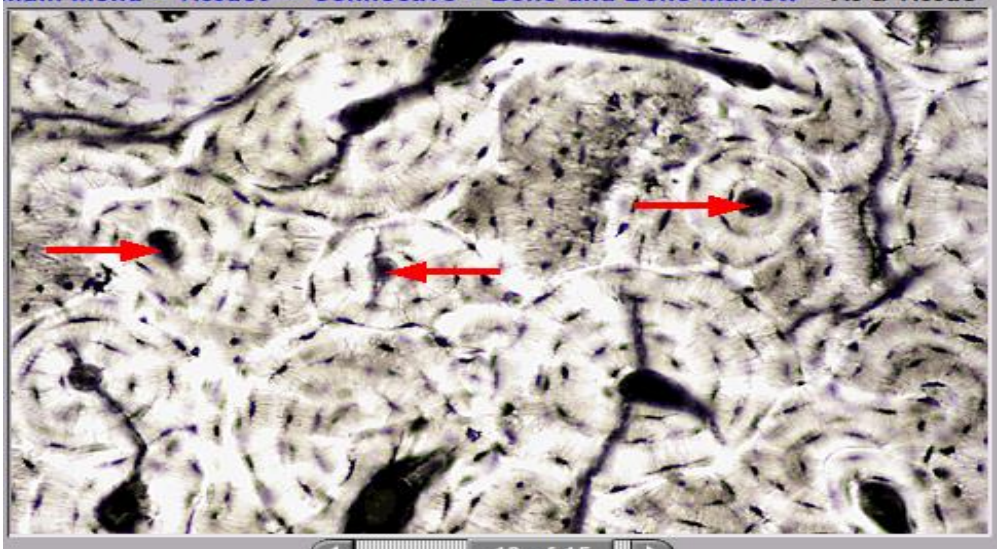
Concentric lamellae within a bone form an osteon (Haversian system) around a central canal called an Haversian canal. Haversian canals are lined by an endosteum and contain a blood vessel. Adjacent Haversian canals are interconncted by perpendicularly oriented tunnels called Volkmann's canals, which convey blood vessels between Haversian systems (osteons).

click to identify:

- Lamellar bone
- Osteocyte lacunae
- Woven bone
- Osteons >
- Haversian canals
- Volkmann's canals

ile View Go Quiz Help

Main Menu > Tissues > Connective > Bone and Bone Marrow > As a Tissue



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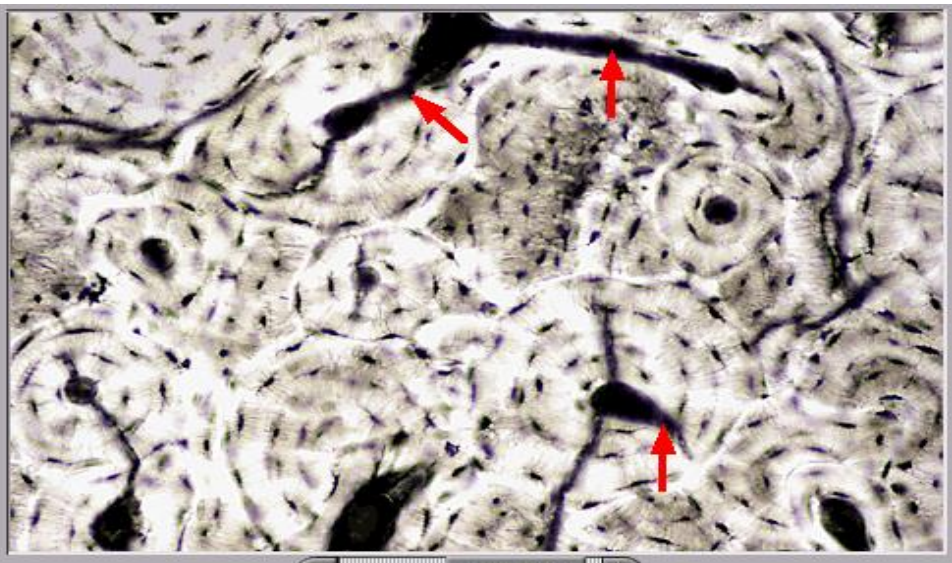
- Osteocyte lacunae
- Woven bone
- Osteons >
- Haversian canals
- Volkmann's canals



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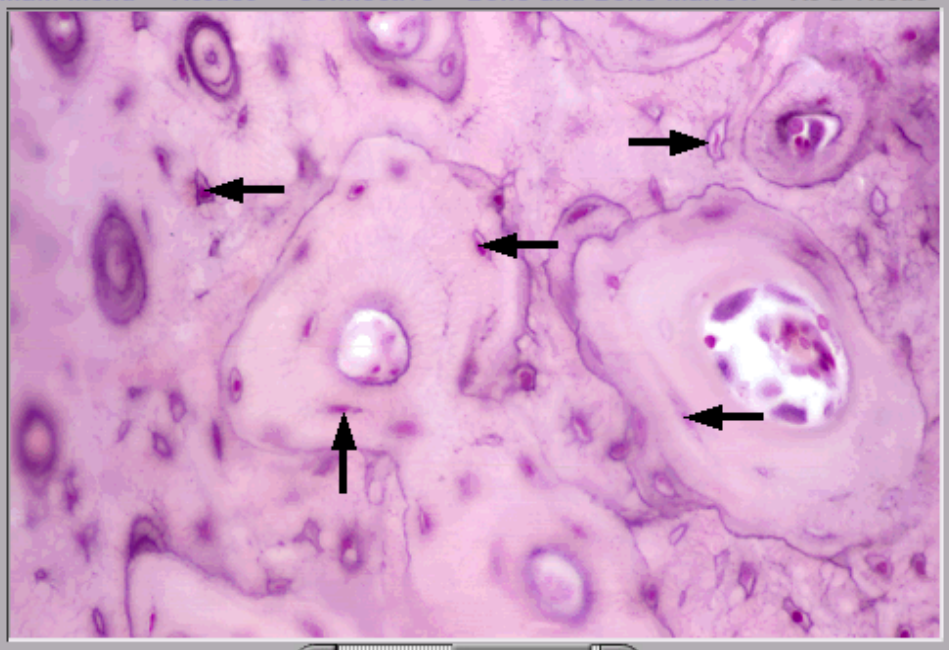
- Lamellar bone
- Osteocyte lacunae
- Woven bone
- Osteons >
- Haversian canals
- > Volkmann's canals

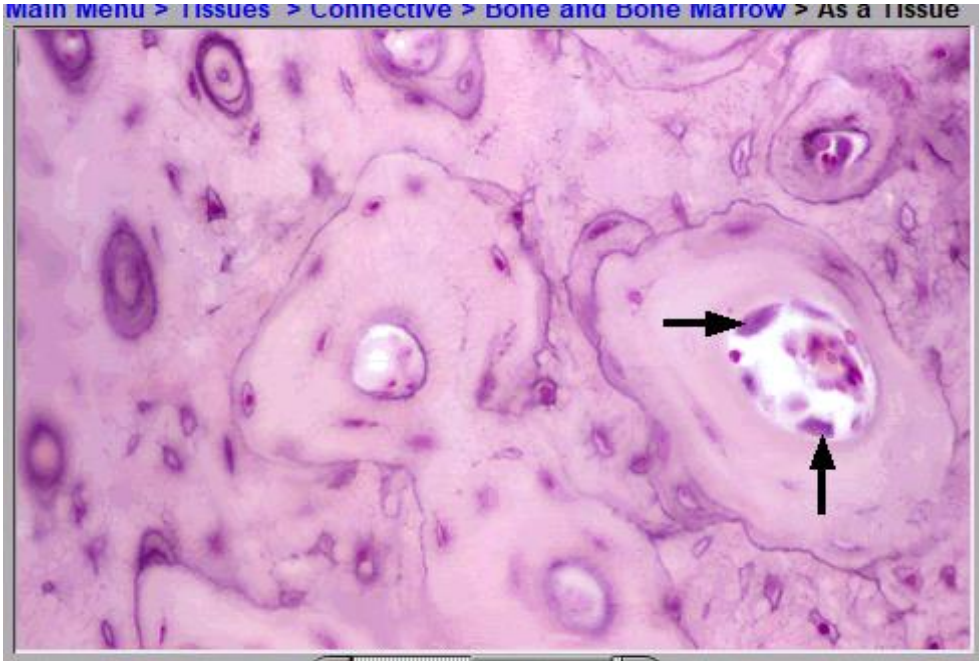


14 of 15

Bone the tissue -- This compact bone is composed of both woven and lamellar bone. Immature, woven bone is gradually resorbed and replaced by the stronger, lamellar, mature bone. During this process, some areas of bone will be composed of both woven bone and lamellar bone. 400x

click to identify:

- > Osteocytes
- Osteoblasts
- Woven bone >
- Lamellar bone >
- Osteons
- Haversian canals
- Blood vessel



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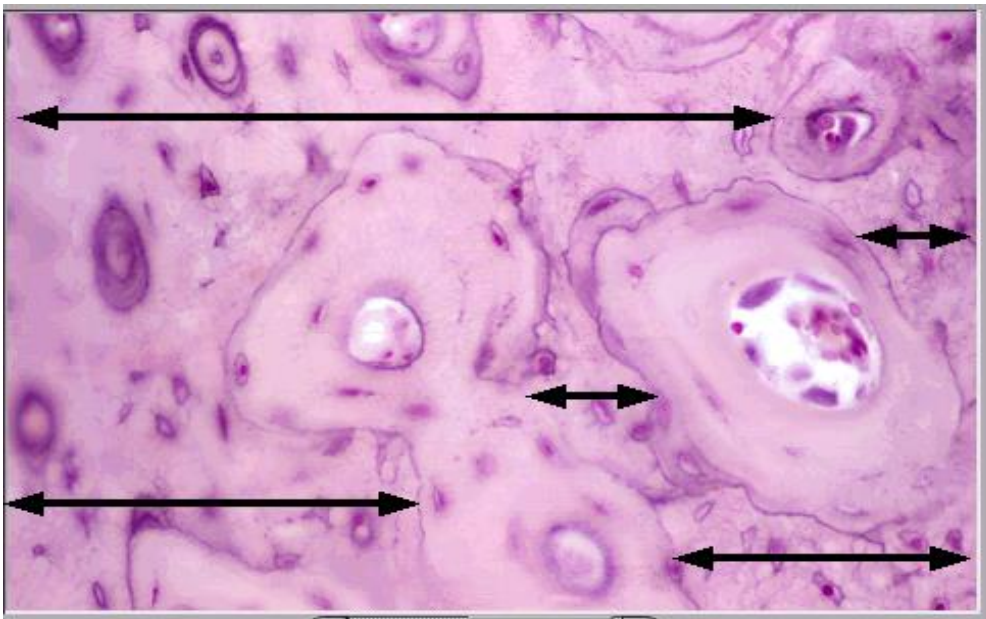

14 of 15

Woven bone can be identified by its bluish tint, the lack of lamellae and the irregular arrangement of the osteocyte lacunae. In woven bone lacunae are rounder than are those of lamellar (adult) bone.

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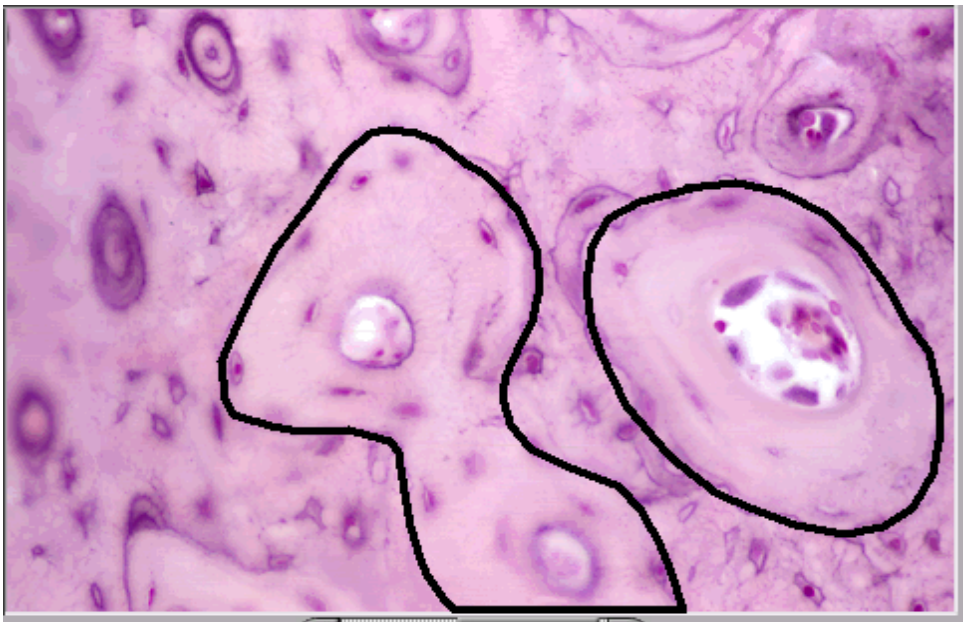

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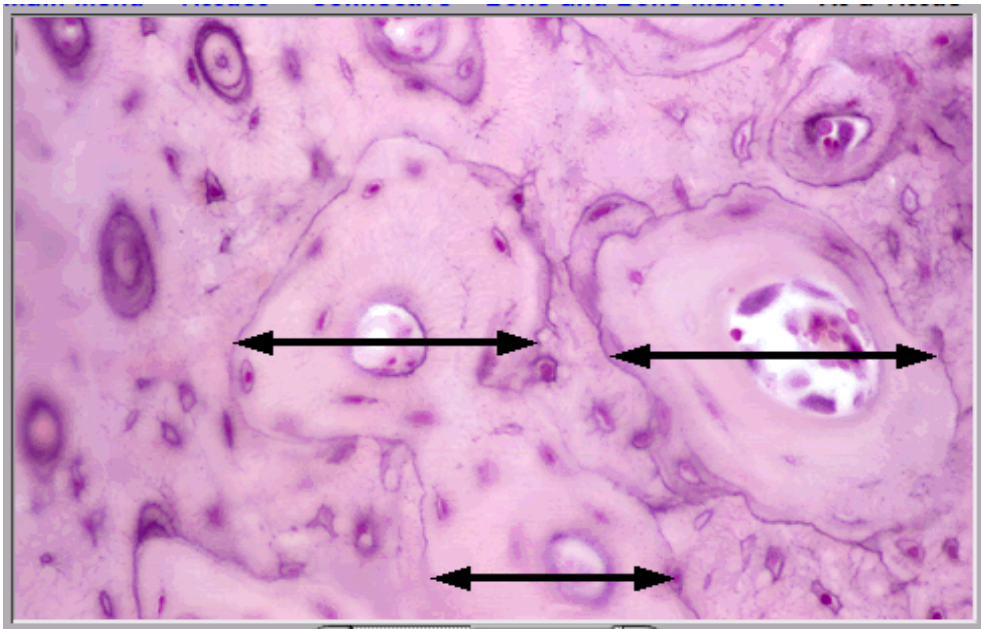

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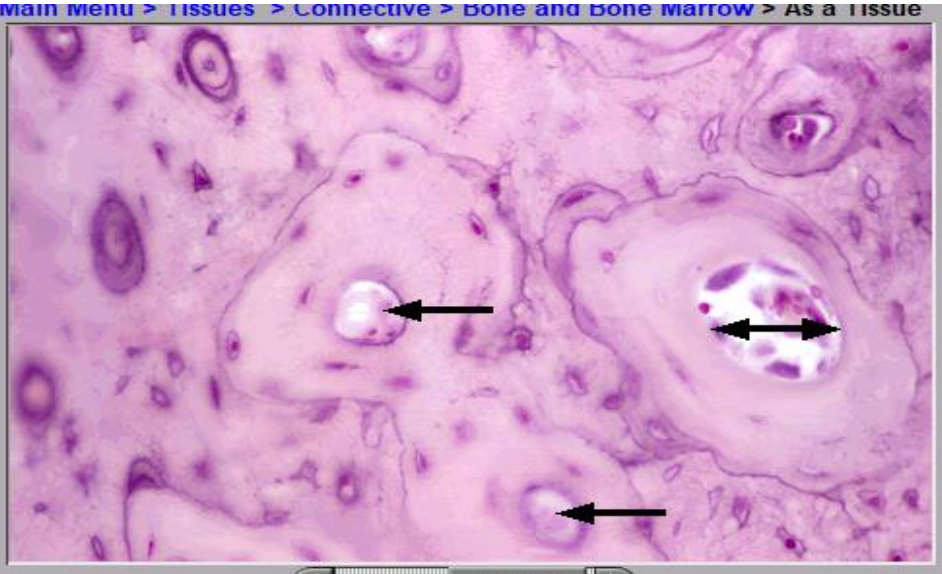

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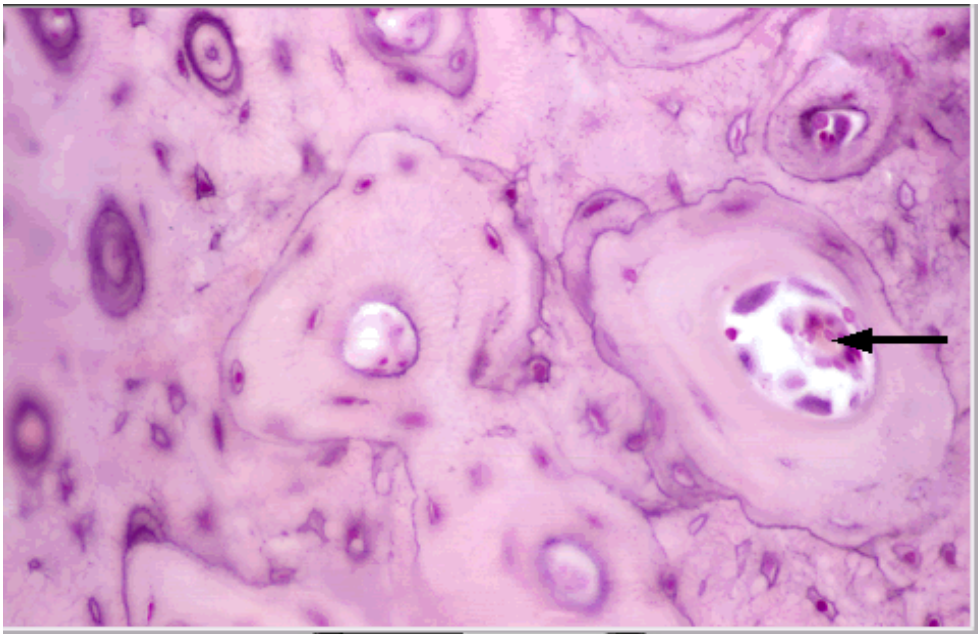

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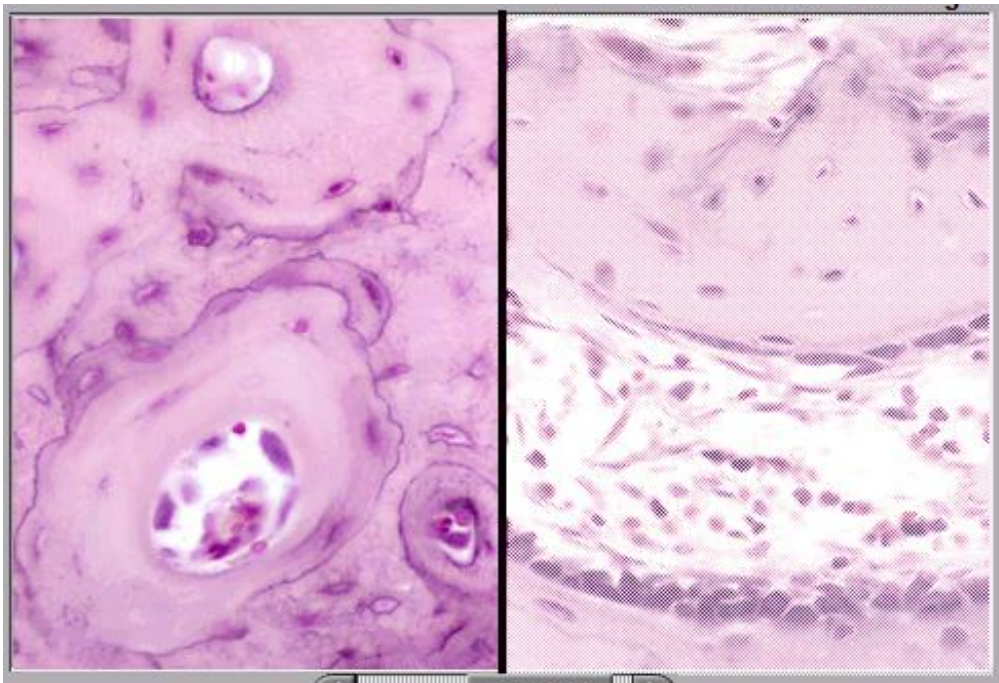
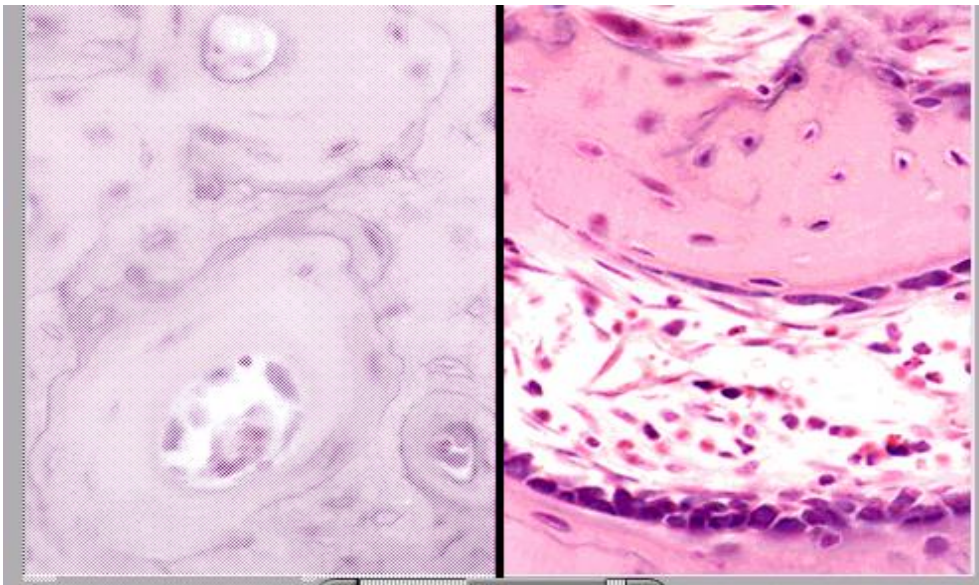


12 of 14

Classification of bone -- Compact and spongy bone differ in their appearance. The ratio of bone:non-bone tissue determines which type of bone is present. In compact bone, bone is the predominate tissue; in spongy bone there is at least as much non-bone tissue as there is bony tissue. 400x, 400x

click to identify:

- Compact bone
- Spongy bone
- Inactive osteoblasts
- Active osteoblasts
- Osteoid
- Osteocytes
- Osteoclast
- Loose CT
- Blood vessels



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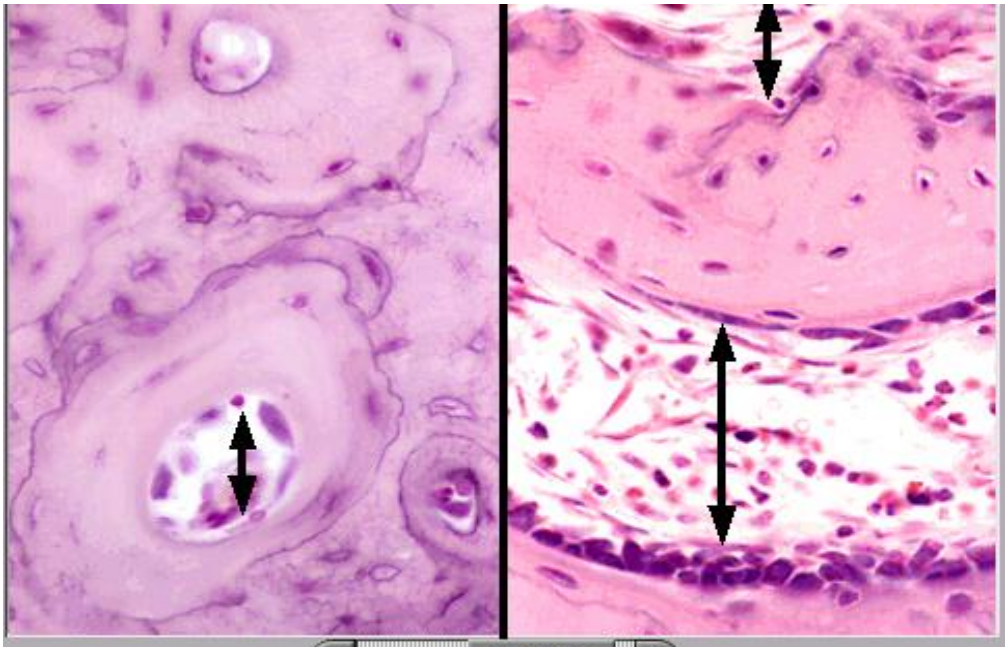

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CHAPTER 2

CELL STRUCTURE AND CELL DIVISION

GENERAL CONCEPTS

I. Heirarchy of body organization

   A. Cells

   B. Tissues (epithelium, muscle, connective, nervous)

   C. Organs (stomach, heart, skin, lung, etc.)

   D. Organ systems (digestive, respiratory, excretory, etc.)

   E. Individual

II. Although there are approximately 200 different cell types in the body, cells are more alike than different. Specialization of function, (e.g., glandular cells for secretion or muscle cells for contraction) is really an emphasis of a function that all cells possess to some degree. In some cases, cells have become so specialized that some functions are lost altogether (e.g., cell proliferation).

III. Cells are the structural units of all living organisms.

   A. Cells vary in size and shape according to location and function.

      1. Cells widely in diameter, from the largest, the mature human ovum (120 microns) to the smallest, the red blood cell (7-8 microns).

      2. Cells shapes. ***(images)***

         a. **Spherical**. Cells in a fluid environment, e.g., blood cells or some nerve cells

         b. **Squamous**. Flattened cells with a width much greater than height. Found at surfaces where rapid exchanges of gases or fluids occur.

         c. **Cuboidal**. Cells shaped like a cube, roughly equal height and width. Often form tubes or tubules.

         d. **Columnar**. Cells shaped like columns, much taller than they are wide. Often function in absorption.

e. **Pyramidal**. Cells shaped like a pyramid. Often found comprising spherical glandular structures.

f. **Stellate**. Star-shaped cells. Possess many slender processes for interaction with multiple cells such as neurons.

g. **Spindle-shaped**. Elongated shape with tapering ends.

B. Cells vary in internal structure depending upon their function.

1. Specialized cells possess abundant internal structures related to their specific function, e.g., contractile filaments in muscle cells or secretory granules in gland cells.

2. Cell polarity. Polarity is a feature of a cell which is exhibited when the organelles are not homogenously distributed in the cytoplasm. This distribution correlates with the function of the cell, e.g., secretion or absorption.

C. Cells vary in their life history, for example, rates of cell renewal.

IV. Major compartments of the cell

A. Cytoplasm. Composed of an aqueous matrix containing the internal structures of the cell, thus allowing for the cytosolic metabolic pathways (e.g., glycolysis) to function.

B. Nucleus

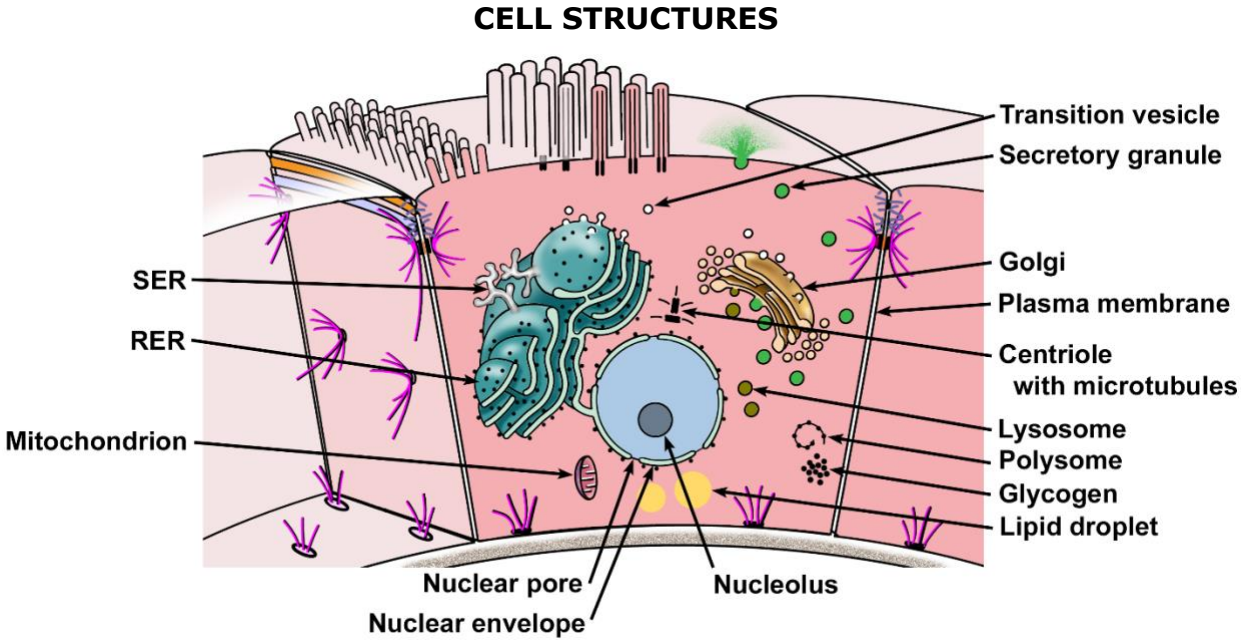


Figure 2.1. Structural features of a typical cell.

CELL MEMBRANES *(images)*

I. All membranes have a similar structure and are referred to as unit membranes. A specialized **unit membrane** forms the surface boundary of the cell and is called the **plasma membrane**. Other membranes are present within the cells, where they form mitochondria, endoplasmic reticulum, or nuclear envelope, for example. The structure of the unit membrane cannot be resolved with the light microscope; however, at high magnification with the electron microscope, it appears as a trilaminar dark-light-dark band.

   A. Fluid mosaic model of membrane structure

      1. **Phospholipid bilayer** consists of two leaflets of phospholipids.

         a. The polar, phosphate head groups face the surfaces of the membrane.

         b. The hydrocarbon tails form the hydrophobic core of the membrane.

      2. Membrane proteins

         a. **Integral membrane proteins** are proteins that extend into one or both of the phospholipid layers. Proteins that extend across both of the phospholipid layers are called transmembrane proteins.

         b. **Peripheral membrane proteins** are either associated with the polar head groups of the phospholipids or with integral membrane proteins. They do not contact the hydrophobic core of the membrane.

      3. **Glycocalyx** is composed of complex carbohydrates on the external surface of the plasma membrane. The carbohydrates are covalently attached to proteins or lipids.

II. Functions of the plasma membrane

   A. Membrane transport

      1. **Diffusion**

         a. Passive diffusion

         b. Facilitated diffusion. Utilizes transmembrane proteins to increase the permeability of the membrane to certain materials.

      2. **Active transport**. Energy-requiring process of moving materials across the membrane.

      3. **Vesicular transport**

a. **Endocytosis**. Internalization of small membrane vesicles formed from the plasma membrane

   i. **Pinocytosis** ("cell drinking"). Uptake of fluid into the cell by a continuous process

   ii. **Receptor-mediated endocytosis**. Requires receptor-ligand binding for vesicle formation and internalization

b. **Phagocytosis** ("cell eating"). Ingestion of large particles (e.g., bacteria) into the cell; prominent in some macrophages and white blood cells.

c. **Exocytosis**. Fusion of cytoplasmic vesicles with the plasma membrane and release of the vesicle contents to the outside of the cell

   i. **Constitutive exocytosis**. Continuous process that renews the plasma membrane.

   ii. **Regulated exocytosis**. Requires an extracellular signal for vesicle fusion and release (e.g., hormone secretion)

d. **Transcytosis**. Uptake of material on one side of a cell followed by transport and release from the opposite surface

B. Cell adhesion. Proteins provide cell-to-cell attachment and cell-to-extracellular matrix anchorage.

C. Intercellular communication. Transmembrane proteins assemble to form pores (gap junctions) between cells.

D. Signal transduction. Following interaction with extracellular signals, e.g., hormones and growth factors, receptor proteins initiate intracellular signaling pathways.

NUCLEUS *(images)*

I. Houses the DNA; produces ribosomes and messenger RNA

II. Components

A. **Nuclear envelope**

1. Composed of two unit membranes, **inner and outer nuclear membranes**, which are separated by the **perinuclear space**; outer

membranes and space are continuous with those of the endoplasmic reticulum.

2. Outer membrane possesses ribosomes.

3. **Nuclear pores**. Perforations in the nuclear envelope, provide direct, bidirectional continuity between the contents of the nucleus and the cytoplasm.

    a. Inner and outer nuclear membranes become continuous at the rim of the pore.

    b. Pores are surrounded by an octet of proteins with a central granule comprising the **nuclear pore complex**.

4. **Nuclear lamina**. Intermediate filaments on the inner nuclear membrane provide support for the nuclear envelope.

B. **Nucleolus**

1. Site of ribosomal RNA (rRNA) synthesis and initial ribosome subunit assembly

2. Subdivisions of the nucleolus

    a. **Nucleolar organizing centers (fibrillary centers)**. Pale staining regions containing DNA sequences that encode rRNA

    b. **Pars fibrosa (dense fibrillar components)**. Electron dense fibrillar regions composed of rRNA transcripts

    c. **Pars granulosa**. Granular-appearing regions composed of maturing ribosome particles

C. **Chromatin**

1. Composed of DNA plus protein, mostly histone protein

2. Chromatin exists in transcriptionally active and inactive states.

    a. **Euchromatin**. Refers to the state of chromatin that is transcriptionally active, dispersed, and pale staining

    b. **Heterochromatin**. Refers to the state of chromatin that is transcriptionally inactive, condensed, and dark staining

D. **Nucleoplasm**. Similar to cytoplasm, an aqueous matrix with cytoskeletal elements

ENDOPLASMIC RETICULUM *(images)*

I. Intracellular system of membranes

II. **Rough endoplasmic reticulum (RER)**

   A. Flattened membrane sacs; can occur singly or as multiple, parallel stacks

   B. Continuous with the nuclear envelope

   C. Possesses ribosomes on the cytoplasmic surface

   D. Site of protein synthesis and some phospholipid synthesis

III. **Smooth endoplasmic reticulum (SER)**

   A. Tubular membranous structures in a meshwork configuration that is continuous with rough endoplasmic reticulum; lack ribosomes

   B. Highly specialized in muscle cells where it is called the **sarcoplasmic reticulum**

   C. Functions

      1. Synthesis of triglycerides, cholesterol, and steroid hormones

      2. Detoxifies drugs

      3. Stores and mobilizes calcium

RIBOSOMES

I. **Ribsomes** are composed of two subunits containing rRNA and proteins.

II. Site of translation of messenger RNA (mRNA) to produce protein

III. Distribution

   A. Free in the cytoplasm. **Polysomes (polyribosomes)**, spiral clusters of ribosomes along a mRNA molecule; synthesize proteins for use in the cytoplasm, mitochondria, peroxisomes, and nucleus

   B. Associated with membranes

      1. Attached to the endoplasmic reticulum or outer nuclear membrane

2. Synthesize:

    a. Proteins for incorporation into secretory granules for release outside the cell.

    b. Hydrolytic enzymes in lysosomes.

    c. Integral membrane proteins.

    d. Proteins that function in the endoplasmic reticulum and Golgi apparatus

GOLGI APPARATUS *(images)*

I. The **Golgi apparatus** is composed of flattened, membranous sacs **(Golgi cisterns)**, usually located near the nucleus. Has no structural continuity with the endoplasmic reticulum

II. Modifies proteins formed in the RER (post-translational modification), for example, glycosylation and phosphorylation, and packages them into vesicles

III. Well developed Golgi complex appears as a distinct, unstained region in the cytoplasm near the nucleus and, for that reason, is often referred to as a **"negative Golgi".**

IV. Components

    A. **Transition/transfer vesicles** deliver proteins synthesized in the rough endoplasmic reticulum to the Golgi

    B. Transition vesicles fuse with the ***cis* or forming face** (convex surface) of the first Golgi cistern.

    C. Proteins move between cisterns in vesicles formed at the margins of the cisterns.

    D. ***Trans* or maturing face** (concave surface), represented by the last Golgi cistern, is the site of final vesicle formation.

    E. **Trans Golgi network**, located at the *trans* face, is the collection of newly formed vesicles that are then transported throughout the cell.

    F. The **cisternal progression model** is an alternate theory by which the initial *cis* face cistern is formed by the fusion of transition vesicles. Thereafter, the cistern and the proteins it contains moves as a unit towards the *trans* face.

Upon reaching the trans face, the cistern breaks up into vesicles thereby contributing to the trans Golgi network

V. Fates of Golgi vesicles from the *trans* Golgi network

A. Fuse with plasma membrane, thereby supplying new lipids and proteins to the membrane

B. Form Golgi hydrolase vesicles ("pre-lysosomes")

C. Form secretory granules

D. Return to the endoplasmic reticulum or Golgi

LYSOSOMES *(images)*

I. **Lysosomes** are membrane-bound vesicles that serve as sites of intracellular digestion.

II. Abundant in cells with high phagocytic activity (macrophages, neutrophils)

III. Formation and function

A. Pre-lysosomal vesicles form at the *trans* Golgi network; contain multiple (>40) inactive hydrolytic enzymes (e.g., proteases, lipases and nucleases)

B. Fuse with endosomes, phagosomes, or autophagosomes, which is followed by a decrease in the luminal pH that activates the hydrolases

C. Hydrolases degrade the contents of the lysosome; undigestible materials are retained in **residual bodies** as **lipofuscin pigment**.

SECRETORY GRANULES *(images)*

I. **Secretory granules** are derived from the *trans* Golgi network.

II. Contain highly concentrated secretory product in single membrane-enclosed structures

III. Transported to the cell surface and fuse with the plasma membrane either in a continuous,
constitutive mode or in a regulated fashion that requires an external signal

IV. **Zymogen granules**. Secretory granules that contain enzymes,

MITOCHONDRIA *(images)*

I. **Mitochondria** (singular, mitochondrion) are sites of ATP production in the cell and are self-replicating.

II. Spherical to ovoid shape, 1-10μm; may be dispersed throughout the cytoplasm or clustered (e.g., at the poles of the nucleus)

III. Composed of **inner and outer unit membranes**. The inner membrane is highly folded to form **cristae**, which provide increased surface area.

   A. Most mitochondria possess cristae that are shaped like thin shelves that project into the matrix.

   B. Mitochondria in steroid hormone-secreting cells have cristae that are tubular.

IV. **Intercristal space**. Located between the cristae and is occupied by **matrix**

V. Contain the enzymes for ATP production. Krebs cycle enzymes are located in the matrix whereas those for the electron transport system are located in the inner membrane.

VI. Matrix contains mitochondrial DNA, RNA, and electron-dense **calcium-containing granules** that, along with the smooth endoplasmic reticulum, provide calcium storage and buffering.

PEROXISOMES

I. **Peroxisomes** are membrane-bound vesicles containing oxidative enzymes (e.g., catalase and beta-oxidation enzymes)

II. Carry out fatty acid oxidation and detoxification of alcohol.

LIPID DROPLETS *(images)*

I. **Lipid droplets** consist of accumulations of cholesterol and triglycerides in the cytoplasm and are not surrounded by a membrane.

II. Can occur as numerous small accumulations or as a single large droplet, as in adipose cells

GLYCOGEN GRANULES *(images)*

I. **Glycogen granules** occur in small clusters or in accumulations as in liver cells and appear highly electron dense; not surrounded by a membrane; stain magenta with the periodic acid-Schiff (PAS) reaction for carbohydrate

II. Storage form of glucose

III. Present in all tissues but highest in liver and striated muscle

PIGMENT

I. **Lipofuscin pigment**

   A. Composed primarily of lipid-containing residues of lysosomal digestion.

   B. Contained within membrane-bound vesicles **(residual bodies)** derived from late-stage lysosomes

II. **Melanin**

   A. Primarily synthesized by **melanocytes** in the skin but can occur in other cell types

   B. **Melanosome**. Membrane-bound vesicle in the cytoplasm containing the melanin pigment

   C. Main pigment responsible for hair and skin color

CYTOSKELETON *(images)*

I. Gives shape and support for the cell, provides cell motility, and facilitates intracellular transport

II. Classification

   A. **Microfilaments**. 4-6 nm filaments composed of actin; function in support of the plasma membrane, cell movement and extension of cellular processes

   B. **Intermediate filaments**. Structurally and chemically heterogeneous among different cell types; 8-10nm filaments that are cell-type specific; function in structural support

   C. **Microtubules**. 18-20 nm tubules composed of cc and p tubulin; multiple functions within the cell. Microtubules form a number of structures in the cell including:

1. **Centriole**. A short rod-like structure composed of nine sets of three microtubules; centrioles occur in pairs near the nucleus and are oriented at right angles to each other. The pair is called a **diplosome** and the region of the cytoplasm where the pair is located is called the **centrosome** or the **microtubule organizing center**.

2. **Basal body**. Structurally similar to a centriole; located at the base of each cilium and flagellum, providing support and serving as the source of the microtubule core of these structures.

3. **Axoneme**. Forms the core of cilia and flagella and provides for the movement of these structures; the axoneme consists of a column of nine pairs of microtubules surrounding two central unpaired microtubules. Each of the paired microtubules is continuous with two of the microtubules of the basal body.

4. **Mitotic spindle**. Individual microtubules that extend from the centrioles to the kinetochore of chromatids during cell division

CELL CYCLE and CELL DIVISION

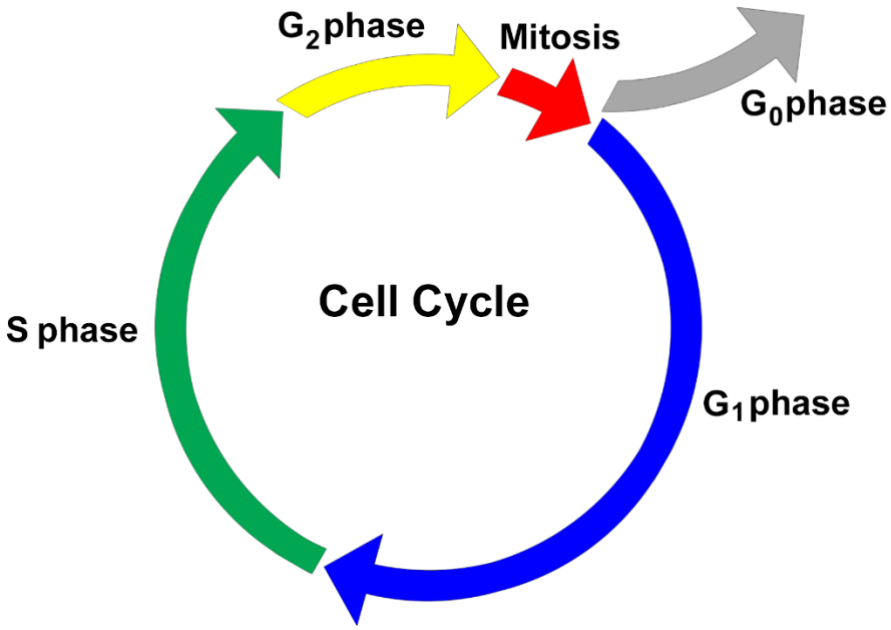


Figure 2.2. The cell cycle

I. The cell cycle is the period that extends from the time a cell comes into existence, as a result of cell division, until it completes its own cell division.

II. Humans have 23 pairs of chromosomes, 22 pairs of autosomes and one pair of sex chromosomes, XX (females) or XY (males). The full complement of 26 pairs of chromosomes is designated 2N.

III. Phases of the cell cycle

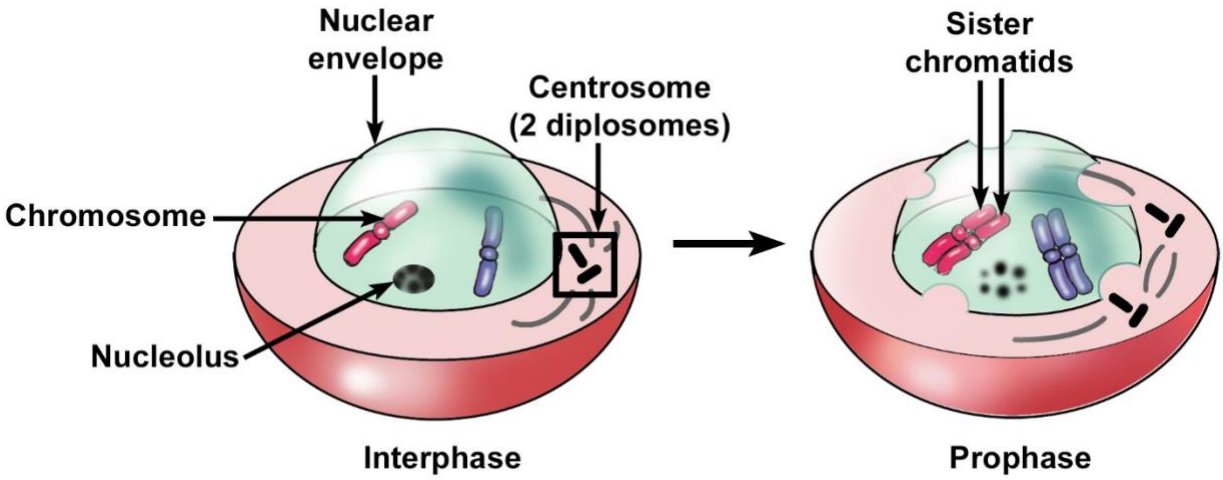
A. **Interphase**. The longest phase of the cell cycle

1. **Go Phase**. Special G_1 phase for quiescent (non-dividing) cells
2. **G_1 Phase**. Initial period of cell growth
3. **S Phase**. Period of DNA synthesis, chromosome duplication, and duplication of the centrioles
4. **G_2 Phase**. Preparation for cell division, which leads to M phase (mitosis)

B. **Mitosis (M phase)** ***(images)***

1. Mitosis is the process whereby cells divide to produce two identical daughter cells. Mitosis is the portion of the cell cycle during which chromosomal segregation and cell division occurs.
2. Phases

a. **Prophase**



i. The initial phase of mitosis, follows the G2 phase of interphase.

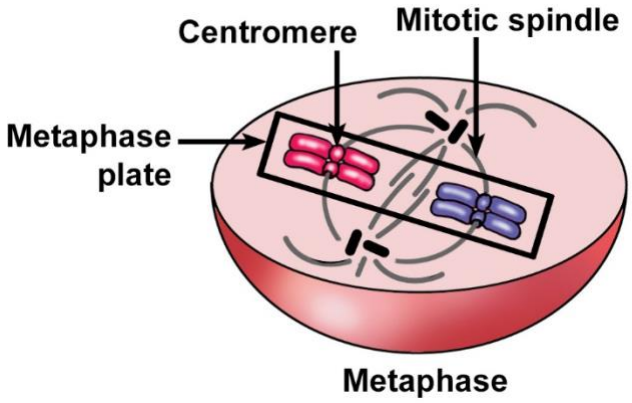
ii. Replicated DNA condenses into paired, visible **chromosomes**; each member of the pair is called a **chromatid**. Chromatids are attached to each other at a junction point called the **centromere** and are called sister chromatids. Adjacent to the centromere, a

protein complex called the **kinetochore** forms, providing an attachment point for the developing microtubules of the mitotic spindle.

iii. The two **centrioles** in the centrosome move apart and migrate toward opposite poles of the cell. The microtubules of the **mitotic spindle** begin to form from each centrosome.

iv. The nuclear envelope disintegrates and the nucleolus disappears. This late stage of prophase is sometimes referred to as prometaphase.

b. **Metaphase**



i. Centrosomes have migrated to opposite poles of the cell

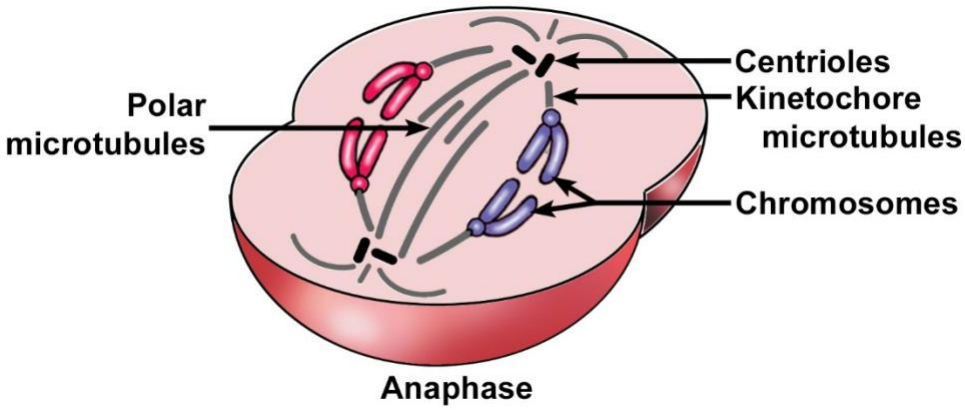
ii. The mitotic spindle is completed, consisting of three types of microtubules.

(a). **Astral microtubles** surround the centrosome

(b). **Kinetochore microtubules** attach to the kinetochore of the sister chromatids and direct chromatid movement to the center of the cell where they align to from the **metaphase (equatorial) plate.**

(c). **Polar microtubules** overlap with opposing microtubules around the metaphase plate and provide the force to drive the spindle poles apart.

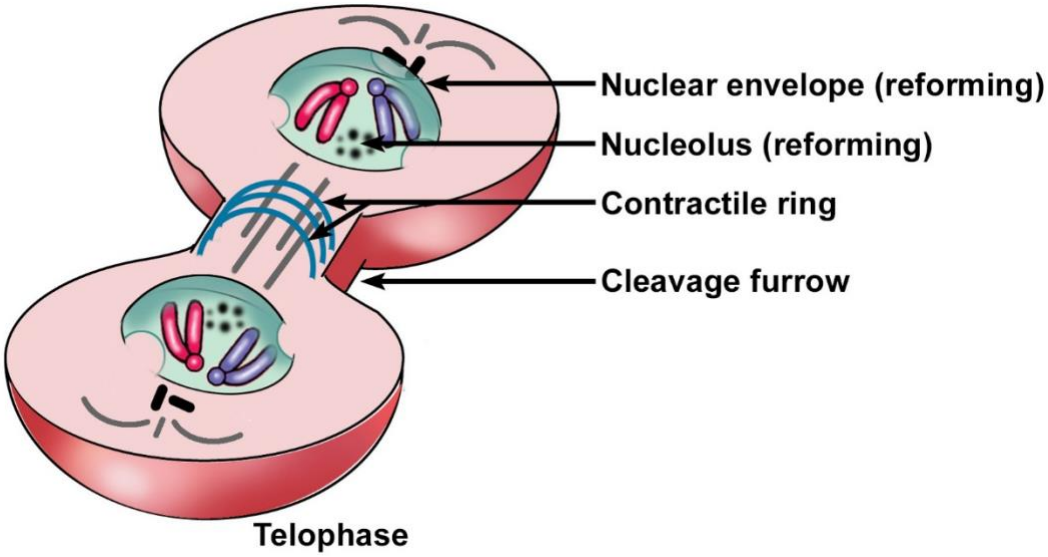
c. **Anaphase**



i. Begins abruptly as sister chromatids separate with each moving towards an opposite pole of the cell. The movement of the chromatids occurs by the pulling forces of the kinetochore microtubules and the pushing force of the polar microtubules to separate the spindle poles.

ii. The end of anaphase is marked by the segregation of an identical set of chromosomes at each spindle pole.

d. **Telophase**



i. Vesicular fragments of the original nuclear envelope that remain in the cytoplasm after prophase reform the nuclear envelope around the chromosomes at each pole. The chromosomal DNA extends and uncoils, losing its stainability.

ii. The nucleolus reforms.

iii. The cytoplasm divides **(cytokinesis)**, forming two identical daughter cells.

(a). A **cleavage furrow** forms marking the eventual separation site of the daughter cells

(b). Separation is accomplished by a **contractile ring** of actin and myosin filaments. Interaction between the filaments tightens the ring and eventually pinches the cell into two daughter cells.

IV. Meiosis

A. This cell division is restricted to the germinal cells in the gonads (ovary and testis) for the production of gametes (ovum and sperm), respectively.

B. Results in reduction of the chromosome number by one-half (1N, haploid). Fusion of the gametes to form a zygote reconstitutes the diploid (2N) number of chromosomes present in somatic cells.

C. Entails two successive cell divisions, **meiosis I (reductional division)**, reducing chromosome number by one-half, followed by **meiosis II (equational division)**, reducing the DNA content by one-half.

D. Results in four, dissimilar daughter cells

E. Divisions of meiosis

1. Meiosis I (reductional division)

a. Prophase. Prophase is more protracted than in mitosis, lasting days to years. It consists of five stages and is marked by the close association of homologous chromosomes (synapsis), allowing exchange of homologous regions between maternal and paternal chromosomes. This exchange process, crossing over, increases genetic diversity. Stages of prophase are:

i. **Leptotene**. Replicated DNA condenses into visible, chromosomes consisting of paired, sister chromatids.

ii. **Zygotene**. Synapsis occurs resulting in the close alignment of homologous pairs of replicated chromosomes. The pairs are tightly bound to each other by protein bridges, the synaptonemal complex, forming bivalents consisting of four chromatids.

iii. **Pachytene**. Crossing over occurs in which fragments of homologous regions of maternal and paternal chromosomes are exchanged. Sites of crossing over, called chiasmata, resemble an

"X" and form connections between paired homologous chromosomes. Crossing over leads to greater genetic diversity in the gametes.

iv. **Diplotene**. Chromosomes further condense and the synaptonemal complex breaks down, leading to a separation of homologous chromosomes.

v. **Diakinesis**. Chromsomes condense to their maximum thickness, the nuclear envelope disappears and the nucleolus fragments.

b. Metaphase. Paired homologous chromosomes, which are still joined by chiasmata, align at the metaphase plate. These pairs, consisting of four chromatids, are called bivalents.

c. Anaphase. Chiasmata break and, unlike mitosis, homologous chromosomes (consisting of attached sister chromatids) separate, thus halving the number of chromosomes from 2N (diploid) to 1N (haploid). Anaphase ends with the segregation of one duplicated chromosome of each homologous pair to each spindle pole.

d. Telophase. Begins by the arrival of one duplicated chromosome of each homologous pair at each spindle pole.

i. Cytokinesis. Cleavage furrow develops, indicating the initial formation of the daughter cells.

ii. Contractile ring forms and its activity result in the formation of two daughter cells, each with a single set of chromosomes (haploid, 1N).

iii. Chromosomal DNA may decondense somewhat but quickly recondenses.

iv. Cells rapidly progress into prophase of meiosis II without passing through a second S phase period.

2. Meiosis II (equational division)

a. Stages

i. Prophase. The events of prophase, Meiosis II parallel those of mitosis.

ii. Metaphase. In each daughter cell, the haploid set of replicated chromosomes (sister chromatids) align at the metaphase plate.

iii. Anaphase. Sister chromatids separate and each is drawn towards

the opposite pole of the cell. Thus, the number of chromosomes does not change (equational division), while the DNA content is halved.

iv. Telophase. Begins with the arrival of a single set of chromosomes at each spindle pole, reformation of the nuclear envelope, decondensation of the chromosomal DNA and the reappearance of the nucleolus. A cleavage furrow develops indicating the initial formation of the daughter cells (cytokenesis).

b. Produces gametes, ovum or sperm, each containing one set of chromosomes (haploid, 1N). However, while the nuclear events producing ova (oogenesis) and sperm (spermatogenesis) are similar, cytoplasmic stages are different between these two processes. In males, a single germ cell produces four sperm; in females, only a single ovum is formed.

COMPARISON OF MEIOSIS AND MITOSIS

I. Mitosis occurs in tissues where cell renewal is required and produces two identical, diploid daughter cells. Meiosis occurs only in the ovary and testis and results in gamete, egg and sperm, production. In meiosis in the male, a single germ cell produces four, dissimilar, haploid daughter cells (sperm); in females, a single germ cell usually produces only a single haploid daughter cell (ovum) plus three non-functional satellite cells.

II. Mitosis consists of a single cell division, while meiosis entails two successive cell divisions, meiosis I (reductional division), reducing the chromosome number by one-half, followed by meiosis II (equational division), reducing the DNA content by one-half.

III. Stages of mitosis and meiosis I

A. Interphase. Interphase is similar in meiosis and mitosis. The first stage of interphase, the G1 stage, is seen here. For diagrammatic purposes, chromosomes are shown in a condensed state.

B. Prophase. Prophase of meiosis I is much longer than in mitosis allowing for crossing over to occur during meiosis.

C. Metaphase. Some differences exist in the alignment of chromosomes at the equatorial plate, but this phase is essentially similar in both processes.

D. Anaphase. In mitosis, sister chromatids of each chromosome separate and move toward the spindle poles, resulting in diploid cells. In contrast, during anaphase of meiosis I, chromatids remain attached and one duplicated chromosome of each homologous pair is pulled to each of the opposite

spindle poles. This process halves the number of chromosomes resulting in haploid daughter cells.

E. Telophase. Cytokinesis is similar for both mitosis and meiosis. Mitosis results in the formation of two identical daughter cells, each with two sets of homologous chromosomes (diploid, 2N). Meiosis I results in the formation of two dissimilar daughter cells, each with a single set of chromosomes (haploid, 1N).

IV. Meiosis II

A. A second division, paralleling meiosis II, does not occur in Mitosis.

B. Meiosis II parallels mitosis except:

1. Cells enter prophase of meiosis II rapidly without any intervening DNA synthesis.

2. At metaphase, a haploid set of replicated chromosomes (sister chromatids) align at the metaphase plate.

3. Cytokinesis produces gametes, ovum or sperm, each containing one set of chromosomes (haploid, 1N)

CHAPTER 3

EPITHELIAL TISSUES

GENERAL CONCEPTS

I. Classification of epithelial tissues

A. **Lining and covering epithelia**

1. Form the boundary between external environment and body tissues

a. Cover body surfaces (e.g., the epidermis of the skin) and lines the lumens of internal organs that open to the exterior of the body

b. Line body cavities (e.g., peritoneal cavity) and covers the exterior of organs that project into these cavities

c. Line blood and lymph vessels

2. Cell shape and number of layers correlate with the function of the epithelium.

B. **Glandular (secretory) epithelia**

1. Develop from a lining or covering epithelium by invagination into the underlying connective tissue

2. Form exocrine and endocrine glands.

II. General features of all epithelial tissues

A. Highly cellular (sparse intercellular space)

B. Numerous intercellular junctions for attachment and anchorage

C. Avascular

D. High proliferative capacity, especially in epithelial membranes, to replace continual sloughing of cells from free surface

E. Most rest on a **basement membrane**. ***(images)***

1. The basement membrane is composed of a **basal lamina** and a **reticular lamina**.

a. The basal lamina is secreted by the epithelial cells and consists of the **lamina lucida** and the **lamina densa**. A similar structure is also present in muscle and nervous tissue, where it is referred to as an **external lamina**.

b. The reticular lamina is secreted by fibroblasts located in the underlying connective tissue.

2. Functions of the basement membrane

a. Provides support and attachment for the epithelial cells

b. Acts as a selective diffusion barrier

F. Free and basal surfaces of epithelia

1. **Basal surface** contacts the basal lamina of the basement membrane.

2. **Free surface** interfaces with the external environment or spaces within the body.

3. **Polarity**. A polarized cell is one that exhibits contrasting properties or structures on opposite sides of the cell. Because epithelial tissues face a free surface, the function of the apical surface is often very different from that at the base of the cell. This diversification is reflected by the non-homogeneous distribution of organelles.

LINING AND COVERING EPITHELIAL TISSUES

METHOD OF CLASSIFICATION

I. Classification by number of layers

A. **Simple epithelium**

1. One cell layer thick

2. All cells rest on the basement membrane (basal surface) and all cells face the free surface.

B. **Stratified epithelium**

1. More than one cell layer thick

2. Only the deepest layer of cells contact the basement membrane and only the superficial-most cells have a free surface.

3. Named according to the shape of the cells at the free surface.

II. Classification by shape of surface cells

A. **Squamous**

1. Cells are much wider than tall, resembling a "fried egg."
2. Nucleus is highly flattened.

B. **Cuboidal**

1. Cells are of equal height and width.
2. Nucleus is spherical.

C. **Columnar**

1. Cells are much taller than they are wide.
2. Nucleus is oval shaped, generally located in the mid to lower portions of the cell.

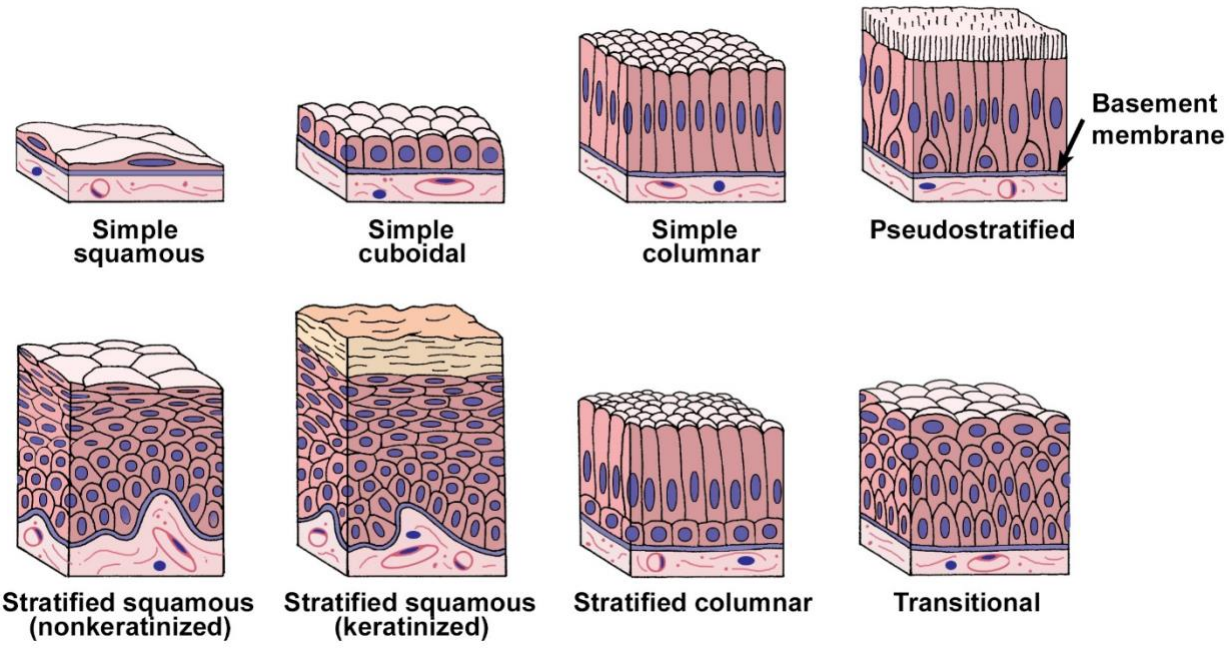


FIGURE 3.1. Types of lining and covering epithelia.

TYPES OF LINING AND COVERING EPITHELIUM

I. Simple epithelial tissues ***(images)***

A. **Simple squamous**

1. Allows for rapid diffusion across the epithelium

2. Forms the lining of blood vessels, alveoli of the lungs, and internal body cavities

B. **Simple cuboidal**

1. Lines and absorbs

2. Forms the walls of ducts and tubules

C. **Simple columnar**

1. Lines and absorbs

2. Forms the lining of the intestines and gall bladder

D. **Pseudostratified**

1. Cells are of various heights. All cells rest on the basement membrane, but only the tallest cells reach the free surface. Variation in height of the cells and the location of nuclei give the appearance of a stratified epithelium. Frequently ciliated.

2. Provides protection and surface transport when ciliated

3. Forms the lining of much of the respiratory tract and much of the male reproductive system

II. Stratified epithelial tissues ***(images)***

A. **Stratified squamous**

1. Protects from physical abrasion and prevents desiccation

2. Types

a. **Nonkeratinized (moist)**. Lining of wet cavities, including the mouth, esophagus, rectum, and anal canal; surface cells are nucleated and living.

b. **Keratinized (dry)**. Epidermis of the skin; surface cells are nonliving.

B. **Stratified cuboidal/columnar**. Lines the larger ducts of exocrine glands.

C. **Transitional**

1. Protective function; constructed to expand with distension of the hollow organs it lines

2. Unique to the urinary system; lines the urinary bladder and ureter

SURFACE SPECIALIZATIONS and CELL JUNCTIONS

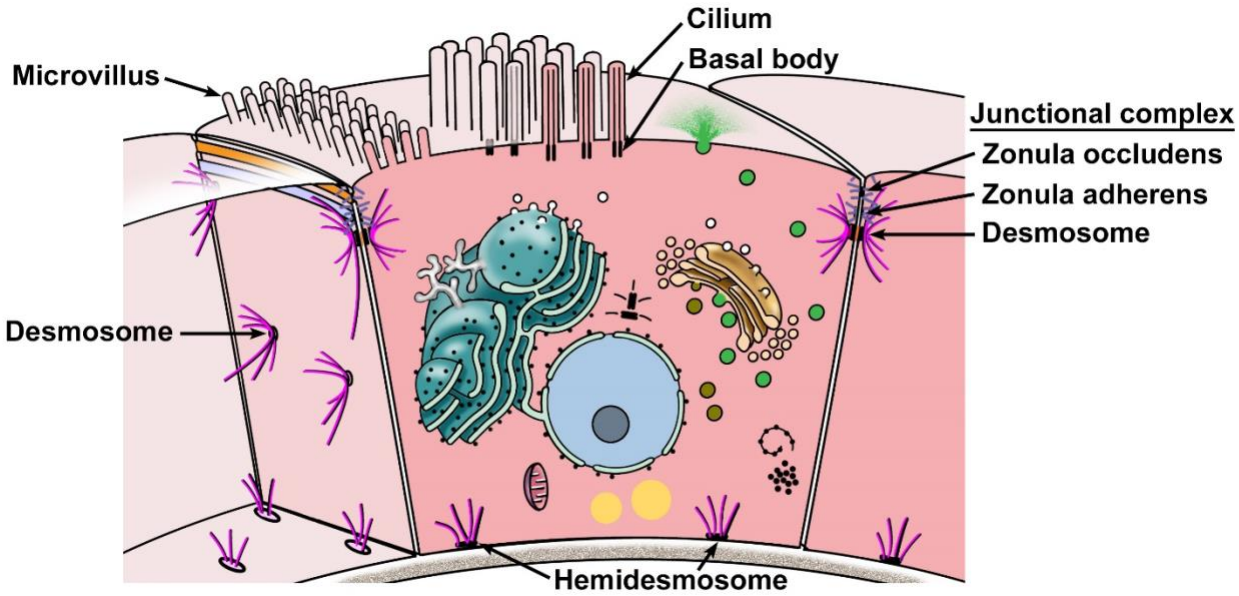


FIGURE 3.2. Cell junctions and surface specializations.

SURFACE SPECIALIZATIONS

I. **Microvilli *(images)***

A. Finger-like extensions from the free surface of the cell, about 1 micron in height

B. Are usually present in large numbers on each cell and, collectively, are called a **brush or striated border**

C. Contain a core of actin microfilaments

D. Are relatively non-motile

E. Increase surface area for absorption

F. Prominent on cells lining the digestive tract and proximal tubules in the kidney

II. **Stereocilia *(images)***

A. Large, non-motile microvilli; not cilia

B. Contain a core of actin microfilaments

C. Increase surface area

D. Present on cells lining the epididymis and ductus deferens in the male reproductive tract

III. **Cilia *(images)***

A. Multiple hair-like extensions from free surface of the cell; 7-10 microns in height

B. Highly motile; beat in a wave-like motion

C. Function to propel material along the surface of the epithelium (e.g., in the respiratory system and the oviduct of the female reproductive system)

D. Core of a cilium is called the **axoneme**, in which nine pairs of microtubules surround two central, individual microtubules (9 + 2 arrangement).

E. The axomene of each cilum originates from a **basal body** that is located at the apex of the cell and is composed of nine triplets of microtubules.

CELL JUNCTIONS *(images)*

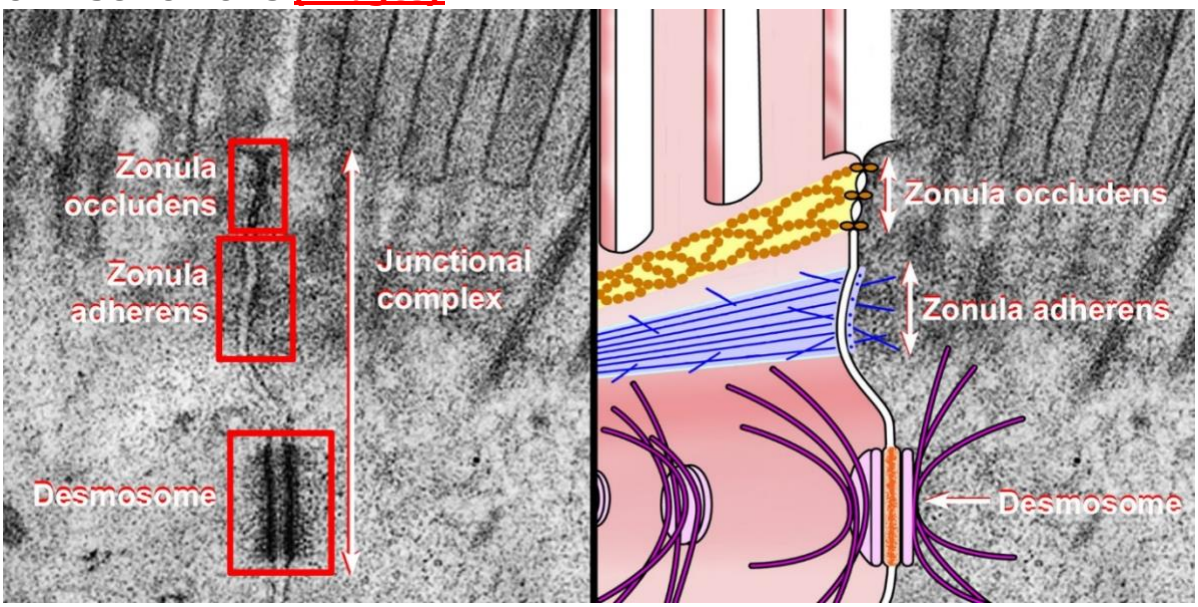


FIGURE 3.4. Cell junctions and surface specializations.

I. Specialized structures of the plasma membrane that:

   A. Attach and anchor cells

   B. Establish apical and basolateral membrane domains by sealing adjacent plasma membranes

   C. Provide channels for ionic and metabolic coupling

II. Not restricted to epithelial cells; cell junctions occur, however, in large number in epithelial tissues to resist the physical forces acting on the cells.

III. Types

   A. **Tight junction (zonula occludens)**

      1. Belt-like, barrier junction around apex of the cell

      2. Provides close apposition of adjacent plasma membranes and occludes the intercellular space

      3. Functions

         a. Prevents diffusion of material between the intercellular space and the lumen of the organ

         b. Establishes apical and basolateral membrane domains in the cell by preventing the lateral migration of proteins in the plasma membrane

   B. **Adherent junctions**

      1. Attach cells to each other or anchor them to the basal lamina; no fusion of the plasma membrane

      2. Types of adherent junctions

         a. **Belt desmosome (zonula adherens)**. Belt-like junction that encircles the apex of the cell like a barrel strap and is located immediately beneath the zonula occludens; serves to attach adjacent cells together; associated with actin filaments.

         b. **Spot desmosome (macula adherens)**. Disk-like junctions scattered over the surface of the cell, which are paired with similar structures in adjacent cells; associated with intermediate filaments (e.g., keratin filaments in epithelial cells).

c. **Hemidesmosome**. Represents a "half desmosome"; these junctions anchor the basal surface of the cell to the basal lamina.

C. **Junctional complex**. Consists of the zonula occludens, zonula adherens, and desmosomes; because these structures cannot be resolved as separate structures at the light microscopic level, they appear as a single, bar-shaped, dark region at the apical corners of adjacent cells. The term **terminal bar** was used by early microscopists to define the zonula occludens and zonula adherens at the light microscopic level.

D. **Gap junction**

1. Gap junctions consist of **connexons**, six transmembrane proteins clustered in a rosette that form a central pore. Connexons from adjacent cells abut one another, forming a continuity between cells.

2. Provides metabolic and electrical continuity (coupling) via the pores between cells

GLANDULAR EPITHELIAL TISSUES

GENERAL CONCEPTS

I. Develop from or within a lining or covering epithelium

II. Secretory cells may

A. Differentiate but remain in the lining epithelium

B. Invaginate into the underlying connective tissue and remain attached to the lining epithelium

C. Invaginate into the underlying connective tissue but lose their connection to the epithelium

EXOCRINE VS. ENDOCRINE GLANDS

I. Major classification of glands, which is based on the method by which their secretory product is distributed

II. **Exocrine glands**

A. Secretory products are released onto an external or internal epithelial surface, either directly or via a duct or duct system.

B. Secretory cells display polarized distribution of organelles.

III. **Endocrine glands**

A. No ducts; secretory products are released directly into the extracellular fluid where they can affect adjacent cells (paracrine secretion) or enter the bloodstream to influence cells throughout the body (endocrine secretion).

B. No polarization of organelles, except the thyroid gland and enteroendocrine cells of the digestive tract

C. Secretory products are called hormones.

METHODS OF PRODUCT RELEASE FROM GLANDULAR CELLS

I. **Merocrine**. Secretory product is released by exocytosis of contents contained within membrane-bound vesicles. This method of release is used by both exocrine and endocrine glands. Examples are digestive enzymes from pancreatic acinar cells and insulin from pancreatic islet cells.

II. **Apocrine**. Secretory material is released in an intact vesicle along with some cytoplasm from the apical region of the cell. This method of release is used by exocrine glands only. An example is the lipid component of the secretory product of the mammary gland.

III. **Holocrine**. Entire cell is released during the secretory process. Cells that are released may be viable (oocyte or sperm) or dead (sebaceous glands). This method of release is used by exocrine glands only.

IV. **Diffusion**. Secretory product passes through the cell membrane without the formation of secretory granules. Examples are steroid hormones. This method of release is used by endocrine glands only.

TYPES OF SECRETORY PRODUCTS

I. Exocrine glands

A. **Mucus**. Thick, viscous, glycoprotein secretion

1. Secretory cells are usually organized into tubules with wide lumens.

2. Cytoplasm appears vacuolated, containing mucigen that, upon release, becomes hydrated to form mucus.

3. Nucleus is flattened and located in the base of the cell.

B. **Serous**. Thin, watery, protein secretion

1. Secretory cells are usually organized into a flask-shaped structure with a narrow lumen, called an acinus.

2. Cytoplasm contains secretory granules.

3. Nucleus is round and centrally located in the cell.

C. Special

1. **Lipid**. Oily secretion (sebum) from sebaceous glands and lipid portion of milk from the mammary gland.

2. **Sweat**. Hypotonic, serous secretion that is low in protein content.

3. **Cerumen**. A waxy material formed by the combination of the secretory products of sebaceous and ceruminous glands with desquamated epidermal cells in the auditory canal

II. Endocrine glands

A. **Derivatized amino acids**, e.g, thyroxine and epinephrine

B. **Peptides and proteins**, e.g., insulin and oxytocin

C. **Steroids**, e.g., testosterone and cortisol

CLASSIFICATION OF EXOCRINE GLANDS *(images)*

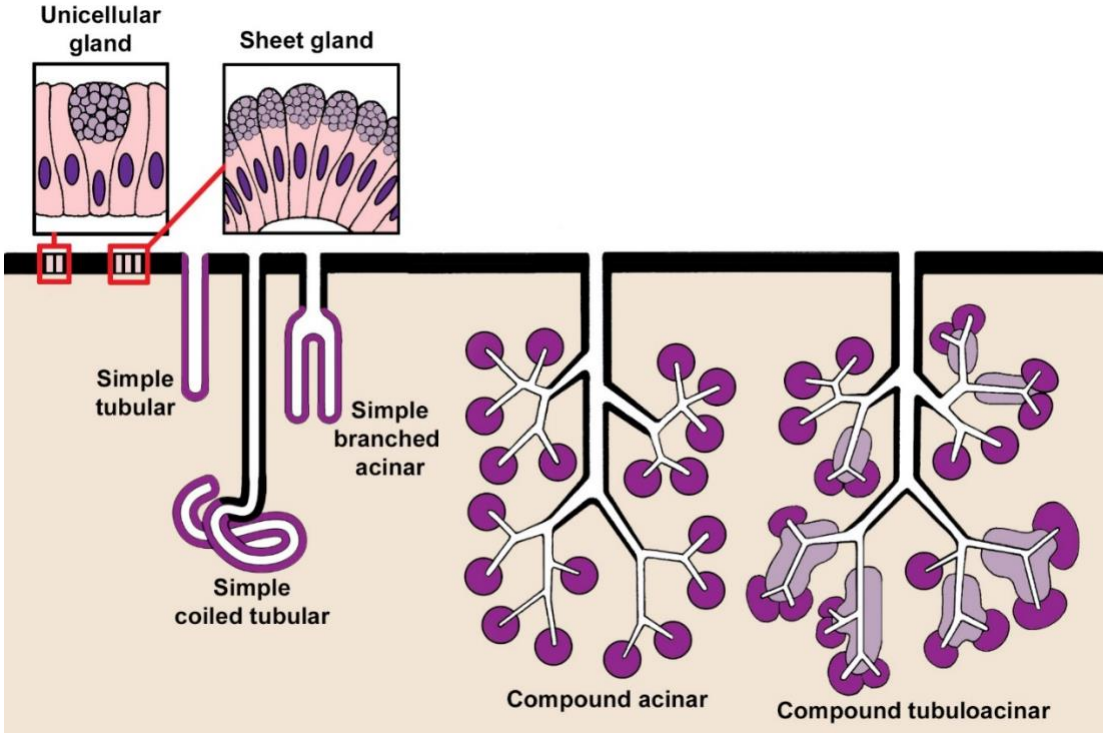


FIGURE 3.4. Types of glands based on their morphology.

I. **Unicellular glands**. Individual cells located within an epithelium, such as **goblet cells** that secrete mucus

II. Multicellular glands

A. **Sheet gland**. Composed of a surface epithelium in which every cell is a mucus-secreting cell. A sheet gland is unique to the lining of the stomach.

B. The remaining multicellular glands are classified according to:

1. The shape(s) of the secretory units

a. Presence of **tubules** only

b. Presence of only **acini** (singular, **acinus**) or **alveoli** (singular, **alveolus**) (these two terms are synonymous), which are flask-shaped structures

c. Presence of both tubules and acini

2. The presence and configuration of the duct

a. **Simple**. No duct or a single, unbranched duct is present.

b. **Compound**. Branching duct system

3. Classification and types of multicellular glands

a. **Simple tubular**. No duct; secretory cells are arranged like a test tube that connects directly to the surface epithelium (e.g., intestinal glands).

b. **Simple, branched tubular**. No duct; tubular glands whose secretory units branch (e.g., fundic glands of stomach)

c. **Simple, coiled tubular**. Long unbranched duct; the secretory unit is a long coiled tube (e.g., sweat glands).

d. **Simple, branched acinar (alveolar)**. Secretory units are branched and open into a single duct (e.g., sebaceous glands).

e. **Compound tubular**. Branching ducts with tubular secretory units (e.g., Brunner's gland of the duodenum)

f. **Compound acinar (alveolar)**. Branching ducts with acinar secretory units (e.g., parotid salivary gland)

g. **Compound tubuloacinar (alveolar)**. Branching ducts with both tubular and acinar secretory units (e.g., submaxillary salivary gland)

SPECIAL FEATURES OF SOME EXOCRINE GLANDS

I. **Serous demilunes**. Consist of a "cap" of serous cells around the end of a mucous tubule; appear half-moon shaped in section

II. **Myoepithelial cells**. Resemble smooth muscle cells in their fine structure but are of epithelial origin; prominent in sweat and mammary glands, they surround secretory units, lying inside the basement membrane, and aid in the expulsion of secretory products from the gland.

DUCT SYSTEM OF COMPOUND, EXOCRINE GLANDS *(images)*

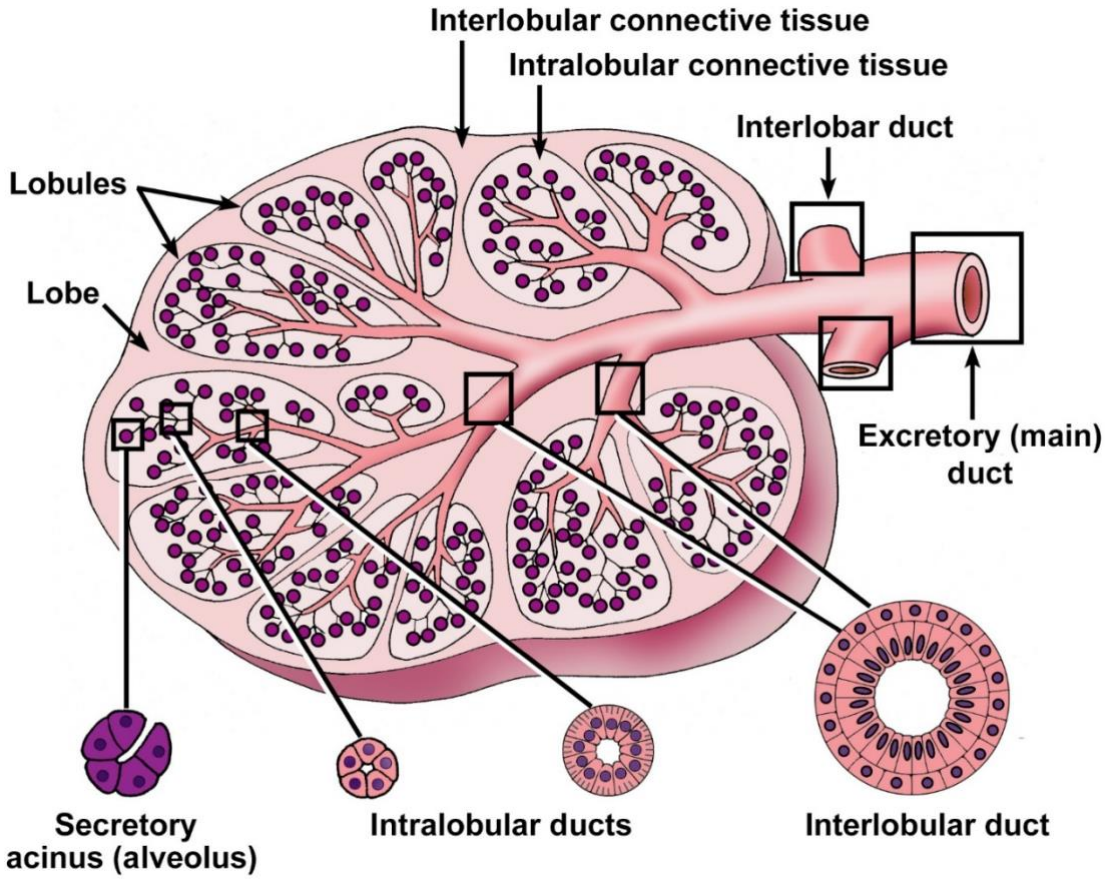


FIGURE 3.5. Structure of a compound gland.

I. **Intralobular ducts**. Contained within a lobule; simple cuboidal to columnar epithelium

II. **Interlobular ducts**. Receive numerous intralobular ducts; located in the connective tissue between lobules; stratified columnar epithelium

III. **Excretory (main) duct**. Macroscopic duct draining the entire gland

ENDOCRINE GLANDS (SEE ALSO CHAPTER 16)

I. No ducts; generally cells are not polarized

II. Occurrence

   A. Unicellular (e.g., enteroendocrine cells of the digestive tract); these cells do show polarity because they are located within an epithelium and secrete away from the free surface of the epithelium.

   B. Small clusters of cells (e.g., islet of Langerhans in pancreas)

   C. Organs (e.g., thyroid gland, adrenal gland)

III. Secretory cells of multicellular glands are usually arranged as plates or cords. The thyroid gland, where the cells form fluid-filled spheres, is an exception to this pattern.

IV. Highly vascular with fenestrated capillaries

V. Secretory products are called hormones. Hormones can be:

   A. Derived from amino acids (e.g, thyroxine and epinephrine)

   B. Peptides and proteins (e.g., insulin and oxytocin)

   C. Steroids (e.g., testosterone and cortisol); steroid-secreting cells display mitochondria with tubular cristae and contain large amounts of lipid droplets and smooth endoplasmic reticulum.

VI. Secrete by the merocrine or diffusion methods only

CHAPTER 4

CONNECTIVE TISSUE PROPER

GENERAL CONCEPTS FOR ALL CONNECTIVE TISSUES

I. Connective tissues are unique in that they provide form and framework to organs and the body. The consistency of the framework they contribute varies from a liquid, to the pliancy of a gel, to the rigidity found in bone. Collectively, connective tissues are the only tissues that possess extensive extracellular components (stroma) in addition to parenchymal cells.

II. Functions

- A. Provides substance and form to the body and organs
- B. Defends against infection
- C. Aids in injury repair
- D. Provides a cushion between tissues and organs
- E. Stores lipids
- F. Provides a medium for diffusion of nutrients and wastes
- G. Attaches muscle to bone and bone to bone
- H. Provide support (cartilage and bone)

III. Components

- A. Cells
- B. Extracellular matrix
  1. Fibers
     - a. Collagen
     - b. Elastic
     - c. Reticular
- C. Ground substance

IV. Types of connective tissue. Classified by the relative abundance, variety and content of the components

A. Connective tissue proper

B. Cartilage (see Chapter 5)

C. Bone (see Chapter 5)

D. Special. Includes adipose, elastic reticular and mucus connective tissues as well as blood and hemopoietic tissue. (See Chapter 6)

COMPOSITION OF CONNECTIVE TISSUES

I. **Cells**. Each type of connective tissue has its own characteristic complement of one or more cell types. Cells specific to each type of connective tissue will be discussed with each tissue.

II. **Extracellular matrix** is synthesized and secreted by resident "blast" cells specific for each connective tissue type (e.g., fibroblasts and chondroblasts); Extracellular matrix is composed of:

A. **Fibers**. ***(images)***

Fiber type	Composition	Properties
Collagen	Collagen I, II	Inelastic, eosinophilic
Reticular	Collagen III	Inelastic, branched, argyrophilic
Elastic	Elastin	Elastic, eosinophilic

1. **Collagen fibers**

a. **Tropocollagen**

i. Collagen molecule subunit consisting of three alpha chains intertwined in a triple helix; collagen types are distinguished by their subunit composition.

ii. Produced by fibroblasts, chrondroblasts, chondrocytes and osteoblasts.

iii. Secreted into the matrix, where they orient themselves into fibrils with a 64 nm repeating banding pattern

b. Major collagen types

i. **Type I**. Fibrils aggregate into fibers and fiber bundles; most

widespread distribution; Forms a component of the extracellular matrix ("interstitial collagen"), tendons, ligaments and capsules of organs.

ii. **Type II**. Fibrils do not form fibers; present in hyaline and elastic cartilages

iii. **Type III**. Fibrils aggregate into fibers; present surrounding smooth muscle cells and nerve fibers. Forms the stroma of lymphatic tissues and organs.

iv. **Type IV**. Chemically unique form of collagen that does not form fibrils; major component of the basal lamina

2. **Elastic fibers**

a. Composed primarily of elastin

b. Elastin forms the central amorphous core of the fiber which is surrounded by microfibrils.

c. Unique chemical properties of elastin provide for elasticity.

d. Elastic fibers occur in nearly all connective tissues in varying amounts and are intermixed with collagen fibers. When present exclusively, they constitute elastic connective tissue.

e. Frequently difficult to differentiate from collagen with conventional stains.

3. **Reticular fibers**

a. Collagen type III fibers

b. Highly glycosylated and stain with silver (argyrophilic)

c. When they are the major fiber fiber type (e.g., in the stroma of lymphoid organs), they constitute reticular connective tissue.

B. **Ground substance**

1. An amorphous substance of variable consistencies from liquid to gelatinous (depending on connective tissue type), in which cells and fibers are embedded. Ground substance can also be impregnated with calcium phosphate to form a rigid solid in the case of bone. The differences in the ground substance among the connective tissues confer unique structural qualities to each connective tissue.

2. Functions

    a. Provides a medium for passage of molecules and cells migrating through the tissue.

    b. Contains adhesive proteins that regulate cell movements and provide anchorage.

    c. Retards passage of bacteria

    d. Provides a medium for passage of molecules and cells migrating through the tissue.

3. Components

    a. **Glycosaminoglycans (GAGs)**

        i. Long, unbranched polysaccharides composed of repeating disaccharide units, which are usually sulfated.

        ii. Large negative charge of the sugars attracts cations, resulting in a high degree of hydration. The matrix formed ranges from a liquid passageway to a viscous shock absorber.

        iii. GAGs are generally attached to proteins to form **proteoglycans**.

        iv. **Proteoglycan aggregate**. Many proteoglycans are attached to hyaluronic acid, which is itself a glycosaminoglycan.

    b. **Adhesive glycoproteins**. For example fibronectin and laminin.

    c. **Tissue fluid**. Contains salts, ions and soluble protein.

GENERAL CONCEPTS FOR CONNECTIVE TISSUE PROPER

I. Connective tissue proper comprises a functionally and structurally diverse group of tissues.

II. Functions

    A. Structural functions of connective tissue proper

        1. Forms a portion of the wall of hollow organs and vessels and the stroma of solid organs

        2. Forms the stroma of organs and subdivides organs into functional compartments

3. Provides padding between and around organs and other tissues

4. Provides anchorage and attachment (e.g., muscle insertions)

B. Provides a medium for nutrient and waste exchange

C. Stores lipid in adipocytes

D. Defends the body and provides immune surveillance via lymphoid and phagocytic cells

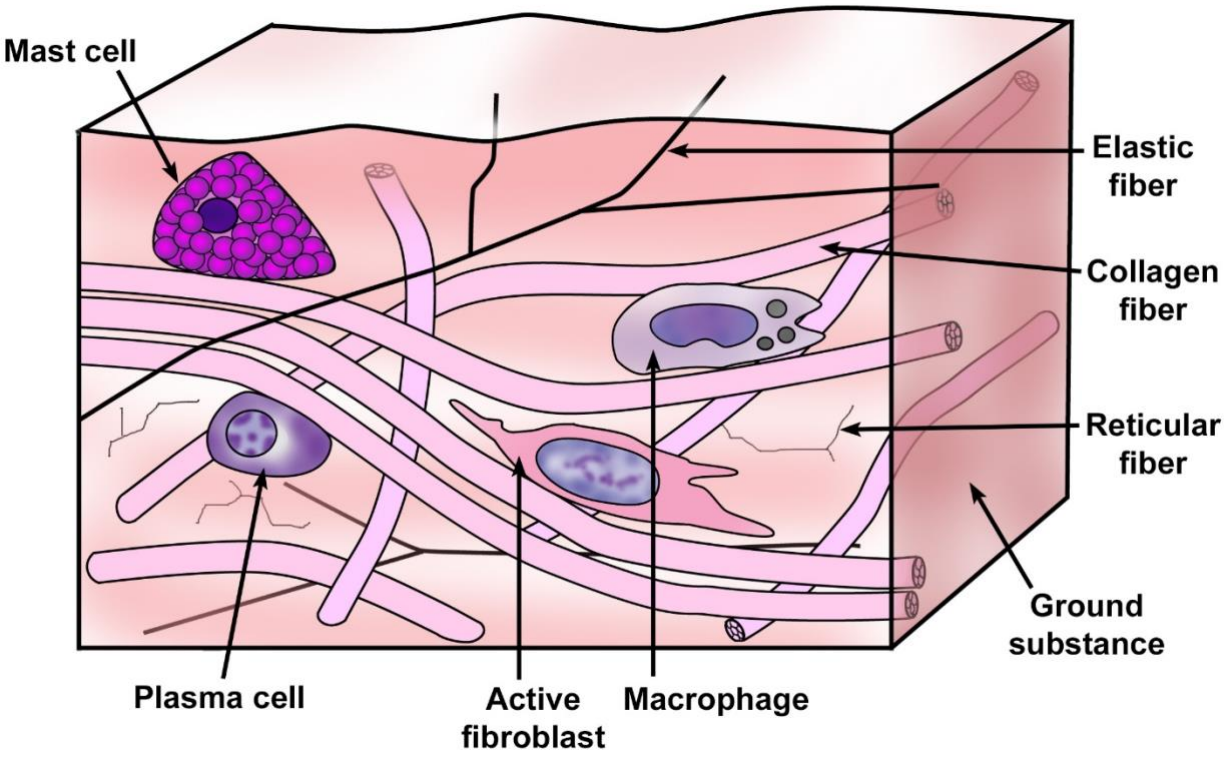


Figure 4.1. Components of connective tissue proper

CELLS OF CONNECTIVE TISSUE PROPER *(images)*

I. Connective tissue cells can be grouped into two major groups, resident and migratory.

A. **Resident cells** are present in tissues continuously and typically exhibit little movement. They can be regarded as permanent residents of the tissue. They can be derived from mesenchyme (embryonic connective tissue) and hemopoietic (bone marrow) tissue.

1. Fibroblasts

a. Synthesize and maintain fibers and ground substance

b. Major resident cell in connective tissue proper

c. Active and inactive fibroblasts

i. **Active fibroblast**

(a). Large, euchromatic, oval nucleus

(b). Cytoplasm not usually visible but contains abundant rough endoplasmic reticulum and Golgi

(c). Either elongated, spindle-shaped cells or stellate in shape, depending on connective tissue type in which they are located

(d). High synthetic activity

ii. **Inactive fibroblast**

(a). Small, heterochromatic, flattened nucleus

(b). Reduced cytoplasm and organelles

(c). Low synthetic activity

2. **Adipose cells (adipocytes, fat cells)**

a. Store lipids

i. Types

(a). **Yellow fat (unilocular)**

1. Each cell contains a single droplet of neutral fat (triglycerides) for energy storage and insulation.

2. Minimal cytoplasm, present as a rim around the lipid droplet

3. Flattened, heterochromatic, crescent-shaped nucleus that conforms to the contour of the lipid droplet

4. Can occur singly, in small clusters or forming a large mass, which is then referred to as adipose connective tissue

(b). **Brown fat (multilocular)**

1. Cells contain numerous, small lipid droplets.

2. Large numbers of mitochondria

3. Present mostly during early postnatal life in humans, abundant in hibernating animals for heat production

3. **Macrophages**

a. Derived from blood monocytes. Monocytes enter connective tissue from the bloodstream and rapidly transform into macrophages that function in phagocytosis, antigen processing, and cytokine secretion.

b. Comprise the mononuclear phagocyte system of the body that includes Kupffer cells in the liver, alveolar macrophages in the lung, microglia the central nervous system, Langerhan's cells in the skin, and osteoclasts in bone marrow.

c. Structure

i. Oval nucleus with an indentation in the nuclear envelope; prominent perinuclear heterochromatin

ii. Cytoplasm usually not visible unless it contains phagocytosed material

4. **Mast cells**

a. Mediate immediate hypersensitivity reaction and anaphylaxis by releasing immune modulators from cytoplasmic granules, in response to antigen binding with cell surface antibodies

b. Structure

i. Round to oval-shaped cells

ii. Round, usually centrally located nucleus

iii. Well-defined cytoplasm filled with secretory granules containing immune-modulatory compounds (e.g., histamine and heparin)

B. **Migratory cells**. Migratory or wandering cells are present only transiently and are mobile. They are white blood cells (WBC's leucocytes), derived from hemopoietic tissue in the bone and function primarily in connective tissue. Migratory cells, for the most part, are able to enter and leave the tissue in response to specific, local stimuli.

1. **Lymphocytes (T and B lymphocytes)**. Small spherical cells with sparse cytoplasm and a round heterochromatic nucleus, often with a small indentation

    a. **B cells**. Enter connective tissue and transform into plasma cells.

        i. Secrete antibodies to provide humoral immunity

        ii. Oval-shaped cells with a round, eccentrically located nucleus with heterochromatin clumps frequently arranged like the numerals on a clock face.

        iii. Basophilic cytoplasm due to large amounts of rough endoplasmic reticulum.

        iv. Well-developed Golgi complex appears as a distinct, unstained region in the cytoplasm near the nucleus and, for that reason, is often referred to as a **"negative Golgi"**.

    b. **T cells**. Provide cellular immunity and modulate the immune response. Primarily located in lymphatic tissues and organs; however can also be present in connective tissue proper.

2. **Neutrophils (polymorphonuclear leukocytes, PMNs)**

    a. Spherical cells with a heterochromatic nucleus with three to five lobes

    b. Pale-staining cytoplasmic granules

    c. Highly phagocytic cells that are attracted to sites of infection

3. **Eosinophils**

    a. Spherical cells with a bi-lobed nucleus

    b. Cytoplasmic granules stain intensely with eosin.

    c. Modulate the inflammatory process

CLASSIFICATION OF CONNECTIVE TISSUES *(images)*

I. Connective tissue proper

A. **Loose (areolar)**

1. Highly cellular, numerous cell types present

2. Fewer and smaller caliber collagen fibers compared with dense
3. Abundant ground substance, allows for diffusion of nutrients and wastes
4. Highly vascularized
5. Provides padding between and around organs and tissues

B. **Dense**

1. Fewer cells, mostly fibroblasts
2. Highly fibrous with larger caliber collagen fibers, provides strength
3. Minimal ground substance
4. Poorly vascularized
5. Types

a. **Dense, irregular connective tissue**. Fiber bundles arranged in an interlacing pattern; forms the capsule of organs and the dermis of the skin

b. **Dense regular connective tissue**. Parallel arrangement of fiber bundles; restricted to tendons and ligaments

II. Connective tissues with special properties

A. **Adipose connective tissue**. Consists of accumulations of adipocytes that are partitioned into lobules by septa of connective tissue proper. Provides energy storage and insulation

B. **Blood and hemopoietic (blood-forming) tissues** (Chapter 6)

C. **Elastic connective tissue**. Regularly arranged elastic fibers or sheets (e.g., the vocal ligament)

D. **Reticular connective tissue**. A loosely arranged connective tissue whose fibers are reticular fibers. Forms the stroma of hemopoietic tissue (e.g., bone marrow) and lymphoid organs (e.g., lymph node and spleen).

E. **Mucus connective tissue**. Embryonic connective tissue with abundant ground substance and delicate collagen fibers; present in the umbilical cord

III. **Supportive connective tissues – Cartilage and Bone** (Chapter 5)

CHAPTER 6

BLOOD AND HEMOPOIESIS

GENERAL CONCEPTS

I. In humans, the average blood volume is 5 liters, constituting 7% of the body mass.

II. Blood is a specialized fluid connective tissue consisting of cells and cell fragments (46% of blood volume) floating in a unique liquid extra-cellular matrix (54% of blood volume).

III. Functions

A. Delivery of nutrients and oxygen to cells and tissues

B. Transport of wastes and carbon dioxide away from cells and tissues

C. Delivery of hormones and other regulatory substances to and from tissues

D. Maintenance of homeostasis by acting as a buffer

E. Thermoregulation

F. Transport of cells of the immune system

IV. Components

A. Cells and cell fragments

1. **Red blood cells (erythrocytes, RBCs)**, produced in the bone marrow

2. **White blood cells (leukocytes, WBCs)**, produced in the bone marrow; some lymphocytes are also produced in lymphoid tissues and organs.

3. **Platelets**. Cell fragments derived from **megakaryocytes** in the bone marrow; contain granules and function in blood coagulation; 150,000-450,000 per microliter blood

B. **Plasma**. Constitutes the extracellular matrix of blood

1. Composed of 90% water and 8-9% protein.

a. Major protein components (plasma proteins)

i. Albumin. Main protein component of plasma, synthesized in the liver. Establishes colloid osmotic pressure within vessels and acts as carrier protein for hormones, metabolites and drugs.

ii. Globulins. Includes gamma globulins which are antibodies secreted by plasma cells.

iii. Fibrinogen. Fiber precursor protein, which is converted into fibrin when blood clots.

2. **Serum**. Yellowish fluid remaining after blood has clotted.

RED BLOOD CELLS

I. Cells resemble bi-concave discs, 6-8 microns in diameter; 4-6 million per microliter of blood

II. Cells are non-nucleated. Cytoplasm contains hemoglobin and cytoskeletal elements but lacks other organelles.

III. Transport oxygen and carbon dioxide

WHITE BLOOD CELLS *(images)*

I. White blood cells are transported in the blood and migrate through vessel walls (diapedesis) to become active in connective tissues; 5-10 thousand per microliter of blood.

II. **Granular leukocytes**

A. **Neutrophil (polymorphonuclear leukocyte, PMNs)**

1. 46-81% of circulating WBCs

2. Spherical cell, 12-15 microns in diameter; pale or unstained cytoplasmic granules; heterochromatic nucleus with three to five lobes

3. Move from the blood to sites of infection

4. Phagocytose bacteria and debris

B. **Eosinophil**

1. 1-3% of circulating WBCs

2. Spherical cell, 12-15 microns in diameter; cytoplasmic granules stain with eosin; bi-lobed nucleus

3. Move from the blood to sites of infection

4. Secrete proteins cytotoxic to parasites, neutralize histamine, and internalize antigen-antibody complexes

C. **Basophil**

1. <1% of circulating WBCs

2. Spherical cell, 12-15 microns in diameter; cytoplasmic granules stain dark blue with hematoxylin; nucleus with 2-3 lobes

3. Similar to mast cells; participate in the hypersensitivity reaction by secreting histamine and heparin

III. **Agranular leukocytes**

A. **Lymphocyte**

1. 24-44% of circulating WBCs

2. Spherical cell, 6-8 microns in diameter; scant cytoplasm and a round heterochroma tic nucleus often with a small indentation

3. T and B lymphocytes

a. **T lymphocytes**. Originate in the bone marrow and mature in the thymus; provide cell-mediated immunity

b. **B lymphocytes**. Originate in the bone marrow and are carried in the blood to lymphoid tissues and organs, where they become activated and proliferate, transform into plasma cells in connective tissue, and provide humoral immunity by secreting antibodies

B. **Monocyte**

1. 3-7% of circulating WBCs

2. Large spherical cells, 12-18 microns in diameter; abundant cytoplasm stains gray-blue; large, U-shaped, euchromatic nucleus.

3. Enter connective tissue, where they transform into macrophages; function in phagocytosis and antigen presentation

HEMOPOIESIS *(images)*

I. General considerations

A. Hemopoiesis is the process of blood cell formation, beginning with a pleuripotential stem cell that subsequently goes through a series of cell divisions and differentiation stages to produce all the mature blood cells.

B. During fetal life, blood cells are first produced in the yolk sac, followed by the hepatic phase when blood cells, mostly erythrocytes, are produced in the liver. The third or bone marrow phase begins during the second trimester and continues until birth.

C. Postnatal hemopoiesis occurring in red bone marrow located in the spongy bone region of long bones, vertebra, ribs, sternum, and the skull, produces erythrocytes, granular leucocytes, B lymphocytes, monocytes and platelets. Lymphocytes are also generated in lymphoid organs and tissues.

D. Blood cells have a relatively short life span and, therefore, new cells are formed continuously.

E. Precursor cell lineage

1. **Stem cells**. Pleuripotential cells that give rise to all the blood cells; divide both to renew their own cell population as well as to form progenitor cells, thus beginning the process of blood cell formation. Hemopoietic stem cells generate two major lineages, **myeloid** and **lymphoid**. Cells of the myeloid lineage consist of erythrocytes (erythropoiesis), granulocytes composed of neutrophils, esosinophils and basophils (granulopoiesis), monocytes (monocytopoiesis) and megakaryocytes (thromopoiesis). The lymphoid lineage includes B and T lymphocytes (lymphocytopoiesis)

2. **Progenitor cells**. Less potentiality than stem cells; committed to the formation of just one or two blood cell lines; have high mitotic activity, dividing to reproduce self and to form precursor cells.

3. **Precursor or blast cells**. Begin morphologic differentiation; display characteristics of the mature blood cells they will form; not self-renewing

4. **Mature blood cells**. Form after several cell divisions of the precursor or blast cells

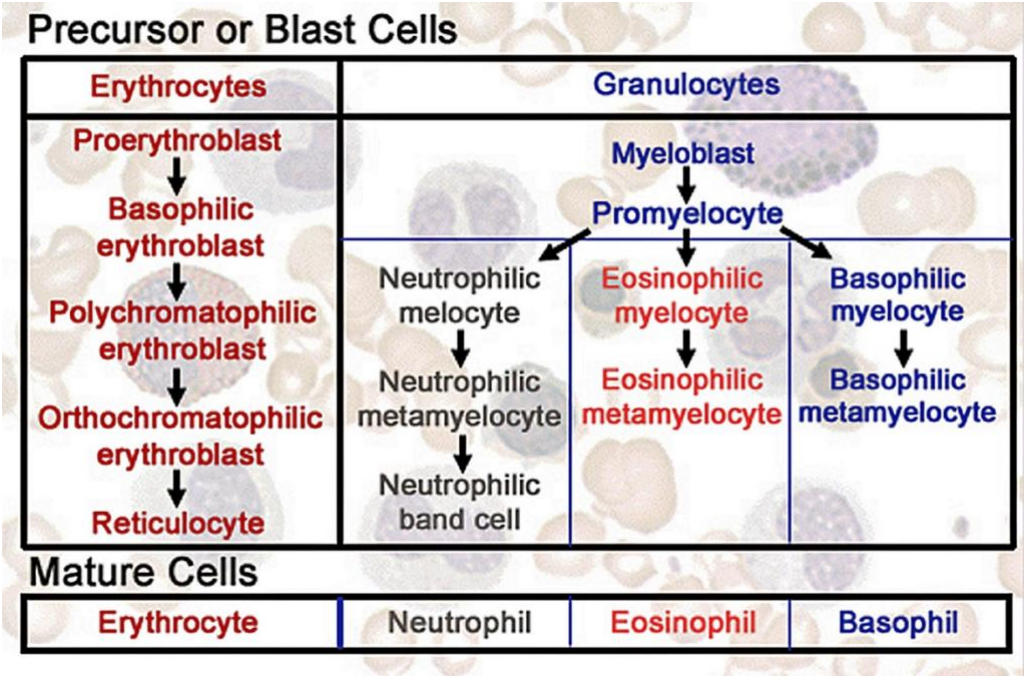


Figure 6.1. Hemopoiesis

II. **Erythropoiesis**: Formation of erythrocytes ***(images)***

A. Process that results in a non-nucleated cell filled with hemoglobin and specialized for transporting respiratory gases

B. Stages. Cells listed in the order in which they form

1. **Proerythroblast**. Precursor cell

2. **Basophilic erythroblast**. Increased numbers of polyribosomes for hemoglobin production results in strong cytoplasmic basophilia; nucleus possesses a "checker-board" chromatin pattern typical of differentiating erythrocytes. The first stage of erythropoiesis that is readily identifiable.

3. **Polychromatophilic erythroblast**. Number of polyribosomes is reduced as hemoglobin accumulates, resulting in the grayish-stained cytoplasm. No further cell division occurs beyond this stage.

4. **Orthochromatophilic erythroblast (normoblast)**. Smallest cells in the series. Continues condensation of the nucleus; increased eosinophilia of the cytoplasm due to accumulating hemoglobin. Nucleus is small, round and very heterochromatic. Late in this stage, the cell extrudes its nucleus.

5. **Reticulocyte**. Non-nucleated cell; small number of polysomes form a reticular

network giving the cytoplasm a lilac color. The polysomes and any other organelles are degraded within one day of release forming mature erythrocytes. In normal blood, reticulocytes constitute about 1% to 2% of the total circulating red cells.

6. **Mature erythrocyte**. Biconcave shape which increases the surface to volume ratio, critical for gas exchange. Erythrocytes transport oxygen and carbon dioxide and remain in the blood for about 120 days.

III. **Granulopoiesis**: Formation of granulocytes ***(images)***

A. Process by which cells first produce nonspecific, azurophilic granules (lysosomes) and then synthesize specific granules containing proteins unique for each granulocyte cell type.

B. Stages. Cells listed in the order in which they form

1. **Myeloblast**. Precursor cell

2. **Promyelocyte**. Earliest identifiable stage. Large euchromatic nucleus. Produces azurophilic (blue) granules that contain lysosomal enzymes

3. **Myelocyte**. Nuclear condensation and the appearance of cell-specific granules containing proteins unique for each of the granular leukocytes. Azurophilic granules still present.

4. **Metamyelocyte**. Cell-specific granules continue to accumulate and the nucleus changes morphology to resemble that of the mature cell. No further cell division after this stage.

5. **Band or stab cell**. Nuclear indentation creates a horseshoe-shaped or band-shaped nucleus. Most apparent in the neutrophilic cell line.

6. **Mature neutrophils, eosinophils, and basophils**. Characterized by lobulation of the nucleus and presence of specific granules unique to each cell type.

IV. **Monocytopoiesis**: Formation of monocytes

A. **Monoblast**. Precursor cell

B. **Promonocyte**. Large cell, up to 18 microns in diameter; nucleus becomes indented and the cytoplasm is basophilic with numerous fine azurophilic granules (lysosomes).

C. **Mature monocyte**

V. **Thrombopoiesis**: Formation of platelets (thrombocytes) **(images)**

A. **Megakaryoblast**. First recognizable cell, resembles a monoblast.

B. **Promegakaryocytes**. Undergo endomitosis, a process where chromosome replication occurs but neither nuclear nor cytoplasmic division follows. Produces polyploidy cells, up to 64N.

C. **Megakaryocytes** are large cells (50-70 microns) with a highly polymorphic nucleus.

D. **Platelets**. Membrane bound cytoplasmic fragments pinched off from the surface of megakaryocytes that aid in blood clotting.

VI. **Lymphocytopoiesis**: Formation of lymphocytes

A. **Lymphoblast**. Precursor cell

B. **Pro-lymphocytes**. Reduction in size from lymphoblast; some remain in the bone marrow to produce B lymphocytes, others leave the bone marrow and travel to the thymus, where they complete their differentiation into T lymphocytes.

BONE MARROW

I. All spaces within bones contain marrow tissue, a specialized connective tissue.

A. **Red marrow**. Blood forming (hemopoietic) red marrow

1. Present in all bone spaces at birth.

2. Converts to yellow marrow with age. Red marrow persists in the pelvic bones, sternum, skull, ribs, and scapulae, as well as in vertebrae. Also occupies the marrow spaces at the proximal ends of long bones such as the femur and humerus.

B. **Yellow marrow**. Fat storage

II. Red marrow releases blood cells and platelets into the circulation throughout life.

CHAPTER 7

MUSCLE TISSUE

GENERAL CONCEPTS

I. Muscle tissue is specialized for the ability to shorten or contract. While all cells possess the cellular machinery necessary for shape change and contraction, these structures are significantly more prominent in muscle cells. For some muscle types, the cells are non-proliferative due to this high degree of specialization and differentiation.

II. Muscle contraction is accomplished by the reciprocating sliding of intracellular filaments composed of actin and myosin.

III. Muscle tissue comprises the "flesh" of the body and much of the walls of hollow organs. Due to its high degree of specialization, unique terms are used for certain structures in muscle cells.

A. **Muscle fibers, Myocytes**. Individual muscle cells.

B. **Sarcoplasm**. The cytoplasm of muscle fibers.

C. **Sarcolemma**. The muscle fiber plasma membrane.

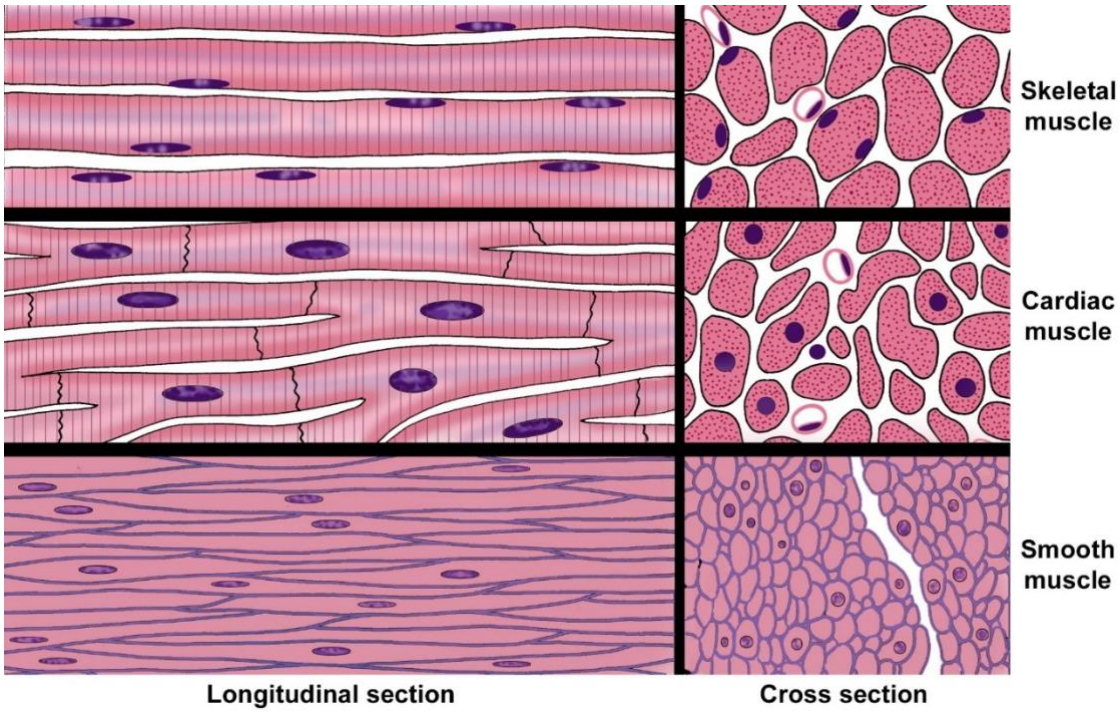


FIGURE 7.1. Comparison of muscle types.

D. **Sarcoplasmic reticulum**. The smooth endoplasmic reticulum.

CLASSIFICATION OF MUSCLE

I. Functional classification is based on the type of neural control.

A. Voluntary

B. Involuntary

II. Structural classification is based on the presence or absence of cross-striations.

A. Striated

B. Nonstriated (smooth)

III. Combined functional and structural classification

A. **Skeletal muscle**

1. **Striated** and **voluntary**

2. Found mostly attached to the skeleton

B. **Cardiac muscle**

1. **Striated** and **involuntary**

2. Composes the majority of the heart wall (myocardium)

C. **Smooth (visceral) muscle**

1. **Nonstriated** and **involuntary**

2. Found mostly in the walls of hollow organs and vessels

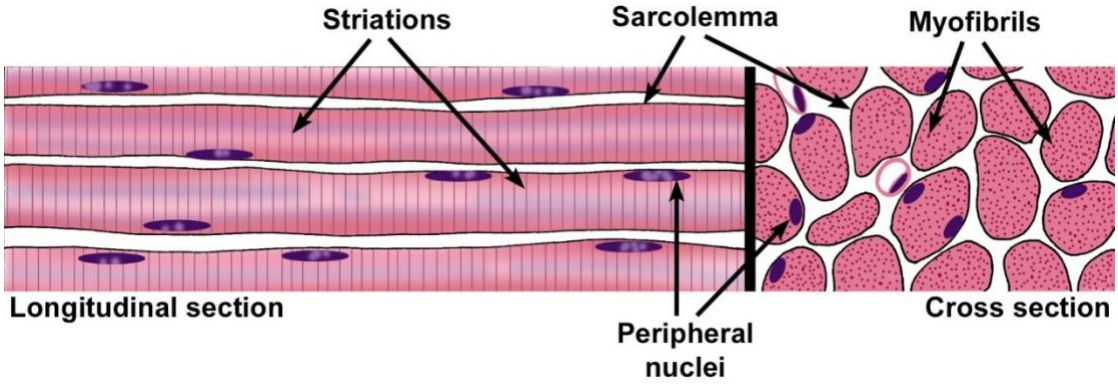


FIGURE 7.2. Skeletal muscle.

SKELETAL MUSCLE *(images)*

I. Connective tissue investments of a skeletal muscle

A. Function

1. Separate muscle into compartments

2. Transmit the force of contraction to insertion points

B. Components

1. **Endomysiuim**. Reticular fibers surrounding each muscle fiber plus the external lamina produced by the muscle fiber

2. **Perimysium**. Dense connective tissue surrounding groups of fibers and dividing the muscle into fascicles

3. **Epimysium**. Dense connective tissue surrounding the entire muscle, blends with the deep fascia and tendons

II. Hierarchy of skeletal muscle organization

A. **Myofilaments**. Visible only with the electron microscope; composed primarily of **actin**, which forms 5-nm wide **thin filaments**, and **myosin**, which forms 15-nm wide **thick filaments**

B. **Myofibrils**. Visible with the light microscope, 1-2 microns wide, oriented parallel to the long axis of the cell; composed of bundles of overlapping myofilaments that are arranged in register, producing an alternating light-dark, striated banding pattern

C. **Muscle fiber**. Specialized term for a muscle cell, 10-100 microns wide; sarcoplasm is filled with hundreds of myofibrils, which are oriented parallel to each other and to the long axis of the muscle fiber.

D. **Muscle fascicle**. Collection of muscle fibers surrounded by perimysium; collections of muscle fascicles are surrounded by the epimysium and form a named muscle such as the biceps brachii or latissimus dorsi.

III. Structure of skeletal muscle fibers

A. Largest fiber type, fibers can be 1-30 mm in length and 10-100 microns in diameter.

B. Each muscle fiber is cylindrical, unbranched, and multinucleated.

C. The multiple nuclei are located at the periphery of the muscle fiber immediately beneath the **sarcolemma**.

D. Extensive smooth endoplasmic reticulum is called the **sarcoplasmic reticulum**.

E. Each fiber is surrounded by an external lamina which contributes to the endomysium of the muscle fiber.

F. Fibers can increase in size (hypertrophy) but not in number (hyperplasia).

G. Fibers show prominent, alternating light and dark bands (cross-striations) due to the alignment and overlap of the myofilaments within myofibrils. Myofilaments within a myofibril are arranged in register and adjacent myofibrils are similarly aligned, causing the banding pattern seen at both the light and electron microscopic levels.

1. **A band** appears dark and contains both actin and myosin myofilaments.

2. **I band** appears light and contains actin myofilaments only.

3. **Z line**, composed of alpha-actinin and Cap Z proteins, is located in the center of the I band and serves as the attachment site for actin myofilaments.

4. **H band** is located in the center of the A band and represents the area where actin myofilaments are not present.

5. **M band** is located in the center of the H band and represents areas of cross-connections between myosin myofilaments.

6. **Sarcomere**

    a. Contractile unit of striated muscle fibers, seen in both skeletal and cardiac muscle fibers

    b. Extends from Z line to Z line

    c. Sarcomeres are repeated in series along the length of each myofibril. Adjacent myofibrils maintain the alignment of sarcomeres.

7. Alterations in sarcomeres during contraction

    a. Sarcomeres shorten as actin myofilaments are pulled past the myosin myofilaments.

    b. Z line interval narrows.

c. Width of H and I bands decreases.

d. A band width remains unchanged.

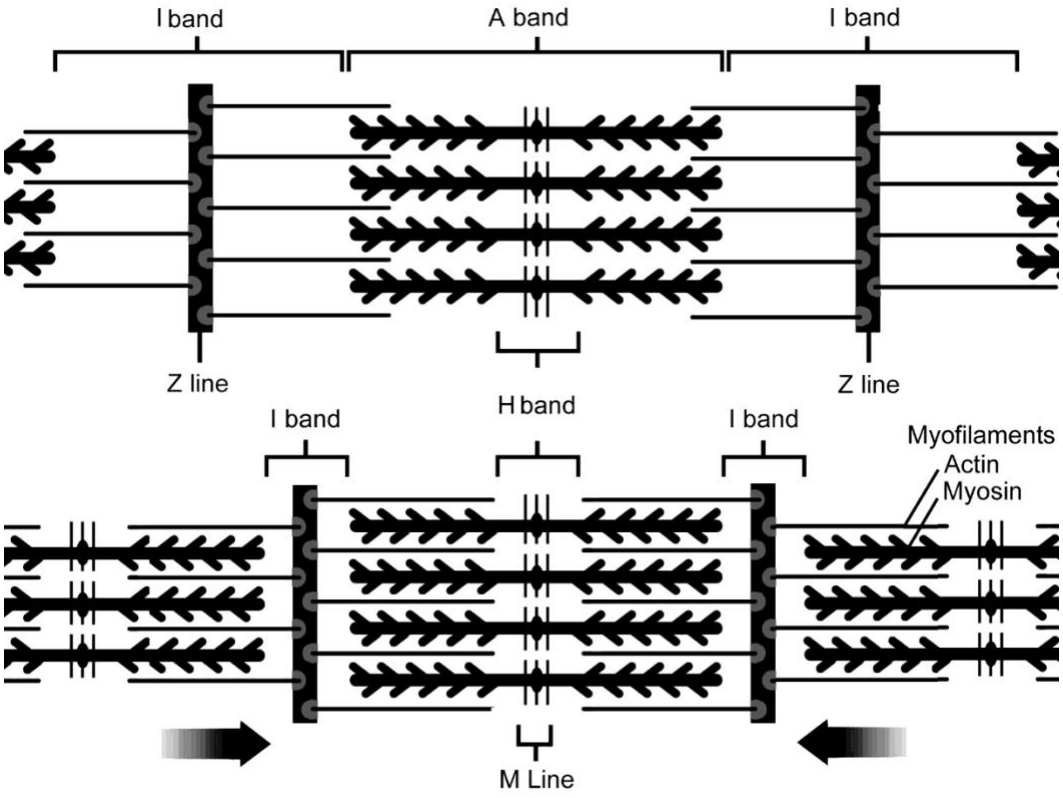


FIGURE 7.3. Sarcomere banding patterns in relaxed (above) and contracted (below) states.

IV. Coordination of skeletal muscle fiber contraction

A. A complex system of intracellular, membranous structures called the triad ensures coordinated contraction throughout the muscle fiber by:

1. Allowing the nervous impulse to penetrate and simultaneously reach all parts of the muscle fiber.

2. Releasing calcium in response to the nervous impulse.

B. **Triads**. Composed of one **T-tubule** plus two adjacent **terminal cisterns** of the sarcoplasmic reticulum.

1. **T-tubules** are invaginations of the sarcolemma that occur at the junction between A and I bands of the myofibrils.

2. **Terminal cisterns** are expanded portions of the sarcoplasmic reticulum

that lie adjacent to the T tubule and release calcium to initiate contraction.

C. Role of triad in muscle contraction

1. A nerve impulse arriving at the muscle fiber depolarizes the sarcolemma at the neuromuscular junction.

2. The membrane depolarization propagates along the sarcolemma and extends down the T-tubules.

3. T-tubule depolarization is transmitted to the terminal cisterns and the remainder of the sarcoplasmic reticulum, causing release of stored calcium.

4. Calcium initiates the interaction between actin and myosin myofilaments, leading to muscle contraction.

5. Calcium is recaptured by sarcoplasmic reticulum during relaxation

V. Mechanism of contraction, sliding filament model

A. Increased calcium concentration triggers the initiation of contraction by allowing the myosin head groups to contact the actin myofilaments.

B. A conformation change of the myosin head groups associated with the hydrolysis of ATP and the release of ADP results in a sliding of the actin myofilament past the myosin. Since the actin filaments are anchored at the Z line, the result of the sliding is shortening of the sarcomere.

VI. Associated structures ***(images)***

A. **Neuromuscular junction (motor end plate)**

1. Specialized "synapse" between the terminals of a motor axon and the sarcolemma of a muscle fiber

2. **Motor unit**. Consists of the motor neuron, its axon, and all the muscle fibers it innervates

B. Proprioceptors

1. Sensory receptors, encapsulated by connective tissue, serve to regulate muscle tension and tone.

2. Types

a. **Muscle spindle**. Highly modified skeletal muscle fibers, intrafusal

fibers, are aligned with and surrounded by normal skeletal muscle fibers.

b. **Golgi tendon organs**. Located within tendons

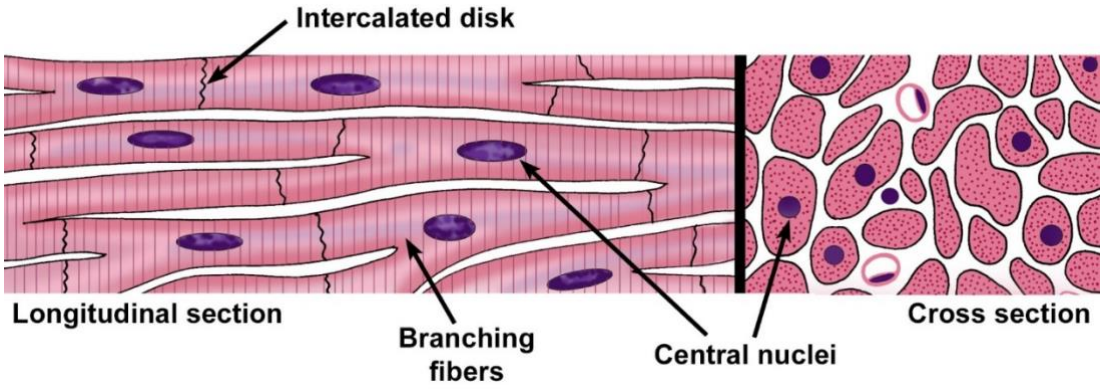


FIGURE 7.4. Cardiac muscle.

CARDIAC MUSCLE *(images)*

I. Cardiac muscle occurs only in the myocardium of the heart and, to a variable extent, in the roots of large vessels where they join the heart.

II. Structure of cardiac muscle fibers

A. Intermediate in size between skeletal and smooth muscle

B. Fibers are cylindrical, branch, and form interwoven bundles.

C. Usually one nucleus per fiber is located in the center

D. Organelles are clustered at the poles of the nucleus.

E. Myofilament organization into myofibrils is identical to skeletal muscle. Cross-striations and bands identical to skeletal muscle are present, but not as prominent.

F. **Intercalated discs**

1. Junctional complexes that are unique to cardiac muscle fibers

2. Consist of specialized cell junctions and interdigitations of the sarcolemma at the ends of the fibers

3. Contain three types of junctions

a. **Fascia adherens**. Similar to zonula adherens of epithelia; serve to attach cardiac muscle fibers and anchor actin filaments of the terminal sarcomeres at the ends of the cell. Acts as a hemi-Z line.

b. **Desmosomes**. Bind ends of fibers together

c. **Gap junctions**. Provide ionic coupling between fibers

G. Highly vascular with large numbers of mitochondria reflecting the high metabolic requirements of cardiac muscle fibers.

H. Fibers are capable of hypertrophy but not hyperplasia.

III. Coordination of cardiac muscle contraction

A. Sarcomeres, myofibrils, and myofilaments are the same as skeletal muscle fibers.

B. T-tubules are located at the level of the Z lines, rather than at junction of A and I bands as in skeletal muscle.

C. No triads. Sarcoplasmic reticulum is not as well developed as in skeletal muscle fibers and does not form terminal cisterns. Contraction is initiated by intracellular calcium release.

D. Contraction can spread through the myocardium due to the presence of gap junctions which allow current to flow from one fiber into another. Heart beat is initiated and regulated by specialized conducting cardiac muscle cells.

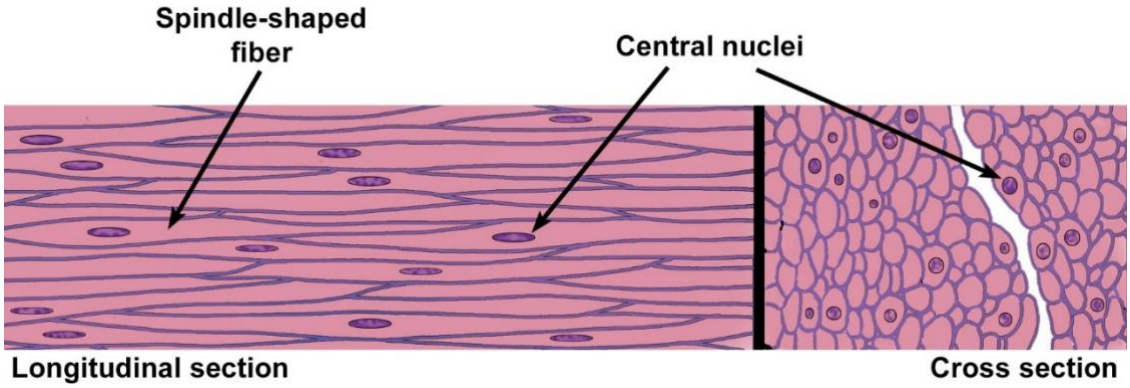


FIGURE 7.5. Smooth muscle.

SMOOTH MUSCLE *(images)*

I. Smooth muscle occurs which form the walls of most hollow organs, including most blood vessels, many respiratory passageway, genital ducts and the ureter.

The wall of the heart is an exception, as the myocardium is composed of cardiac muscle.

II. Structure of smooth muscle fibers

A. Smallest fiber type, length varies from 20 microns in blood vessels to 500 microns in the uterus

B. Unbranched spindle-shaped fibers are elongated with tapering ends.

C. Possess a single, centrally placed, oval nucleus, which can appear spiraled or "inch-worm"-shaped when the fiber is contracted.

D. Organelles are clustered at the poles of the nucleus.

E. Nonstriated; no myofibrils are present.

F. External lamina is present along with reticular fibers.

G. Abundant gap junctions

H. Capable of both hypertrophy and hyperplasia

III. Organization of the contractile proteins

A. Actin and myosin myofilaments are present, but they are not organized into myofibrils.

B. Myofilaments overlap as in striated muscle and crisscross throughout the sarcoplasm, forming a reticulum.

C. **Dense bodies**

1. Serve as insertion points for myofilaments to transmit the force of filament sliding

2. Contain alpha-actinin and, thus, resemble Z lines of striated muscle

3. Present in the cytoplasm and associated with the sarcolemma

IV. Coordination of smooth muscle contraction

A. No T-tubules are present; however, fibers do have a rudimentary sarcoplasmic reticulum.

B. Sliding filament mechanism. Regulated by intracellular release of calcium but with some differences from striated muscle fibers

V. Types of smooth muscle

A. **Visceral smooth muscle**

1. Occurs in sheets in the wall of hollow organs (e.g., digestive tract)
2. Minimally innervated; contraction spreads in peristaltic waves facilitated by large numbers of gap junctions.
3. Specialized for slow, prolonged contraction

B. **Multiunit smooth muscle**

1. Richly innervated, fewer gap junctions than visceral smooth muscle
2. Specialized for precise, graded contraction (e.g., iris of the eye)

CHAPTER 8

NERVOUS TISSUE

GENERAL CONCEPTS

I. Nervous tissue is highly specialized to employ modifications in membrane electrical potentials to relay signals throughout the body. Neurons form intricate circuits that:

   A. Relay sensory information from the internal and external environments.

   B. Integrate information among millions of neurons

   C. Transmit effector signals to muscles and glands.

II. Anatomical subdivisions of nervous tissue

   A. **Central nervous system (CNS)**

      1. **Brain**

      2. **Spinal cord**

   B. **Peripheral nervous system (PNS)**

      1. **Nerves**

      2. **Ganglia (singular, ganglion)**

CELLS OF NERVOUS TISSUE

I. **Neurons**

   A. Functional units of the nervous system; receive, process, store, and transmit information to and from other neurons, muscle cells, or glands

   B. Composed of a cell body, dendrites, axon and synapses

   C. Form complex and highly integrated circuits

II. **Supportive cells**

   A. Provide metabolic and structural support for neurons, insulate neurons via a

myelin sheath, maintain homeostasis, and perform phagocytic functions

B. Comprised of astrocytes, oligodendrocytes, microglia, and ependymal cells in the CNS; comprised of Schwann cells in the PNS

STRUCTURE OF A "TYPICAL" NEURON

I. **Cell body (soma, perikaryon)**

A. **Nucleus**

1. Large, spherical, usually centrally located in the soma

2. Highly euchromatic with a large, prominent nucleolus

B. **Cytoplasm**

1. Well-developed cytoskeleton

a. Intermediate filaments *(neurofilaments)*

b. Microtubules

2. Abundant rough endoplasmic reticulum and polysomes *(***Nissl substance***)*

3. Well-developed Golgi apparatus

4. Numerous mitochondria

II. **Dendrite(s)**

A. Usually multiple and highly branched at acute angles

B. May possess **spines** small membranous elevations which form excitatory synapses

C. Collectively, form the majority of the receptive field of a neuron; conduct impulses toward the cell body

D. Cytoplasmic components

1. Microtubules and neurofilaments

2. Rough endoplasmic reticulum and polysomes

3. Smooth endoplasmic reticulum

4. Mitochondria

III. **Axon**

A. Usually only one per neuron

B. Generally of smaller caliber and longer than dendrites

C. Branches at right angles, fewer branches than dendrites

D. Cytoplasmic components

1. Microtubules and neurofilaments

2. Lacks rough endoplasmic reticulum and polysomes

3. Smooth endoplasmic reticulum

4. Mitochondria

E. **Axon hillock**. Region of the cell body where axon originates

1. Devoid of rough endoplasmic reticulum and so stains pale

2. Continuous with **initial segment** of the axon that is a highly electrically excitable zone for initiation of nervous impulse

F. Usually ensheathed by supporting cells

G. Transmits impulses away from the cell body to

1. Neurons

2. Effector structures such as muscle and glands

H. Branches extensively near its target, each branch ends in a swelling, the terminal bouton, which is the presynaptic element of a synapse

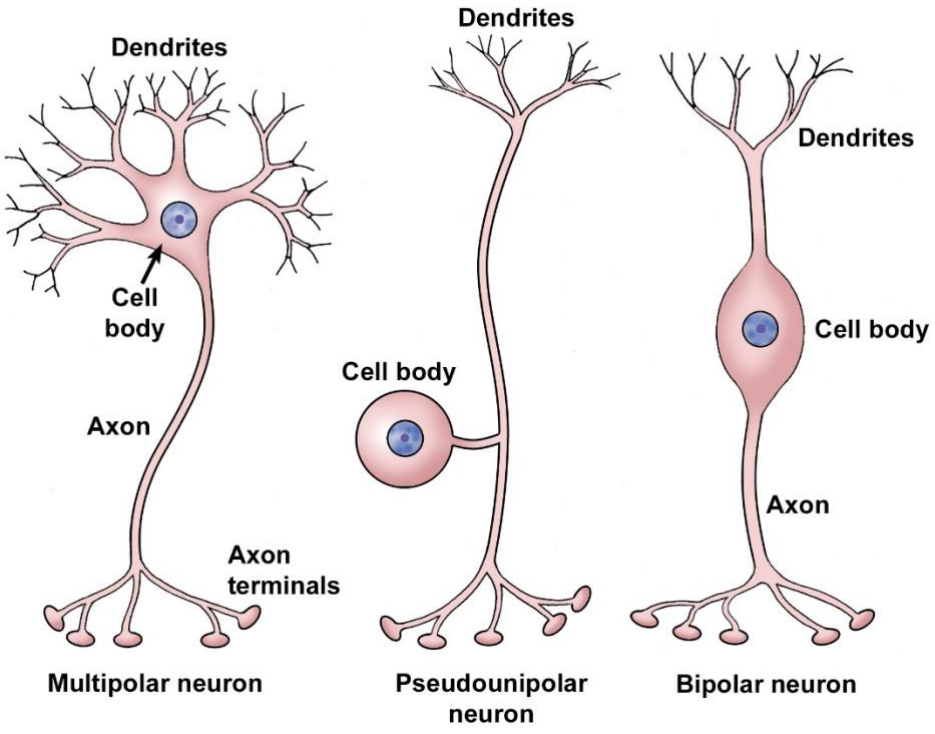


FIGURE 8.1. Types of neurons based on shape.

TYPES OF NEURONS BY SHAPE AND FUNCTION *(images)*

I. **Multipolar neuron**. Most numerous and structurally diverse type

   A. Efferent. Motor, carrying impulses out of the CNS or innervating smooth muscle from autonomic ganglia

   B. Integrative function, axons remain in the CNS

   C. Found throughout the CNS and in autonomic ganglia in the PNS

II. **Pseudounipolar neuron**

   A. Afferent. Sensory function, carrying impulses from peripheral receptors into the CNS

   B. Found in selected areas of the CNS and in sensory ganglia of cranial nerves and spinal nerves (dorsal root ganglia)

III. **Bipolar neuron**

   A. Afferent. Sensory function

B. Found associated with organs of special sense (retina of the eye, olfactory epithelium, vestibular and cochlear ganglia of the inner ear)

C. Developmental stage for all neurons

ARRANGEMENT OF NEURONAL CELL BODIES AND THEIR PROCESSES

I. In both CNS and PNS, cell bodies are found in clusters or layers and axons travel in bundles. These groupings are based on common functions and/or common connections.

	Group of cell bodies	**Bundle of processes**
Central nervous system	Nucleus or cortex (gray matter)	Tract (white matter)
Peripheral nervous system	Ganglion	Nerve

SYNAPSE

I. The function of the synapse is to alter the membrane potential of the postsynaptic target cell to either facilitate or inhibit the likelihood of the stimulus to be propagated by the postsynaptic cell. Most neurons receive thousands of synaptic contacts, both stimulatory and inhibitory, and the algebraic sum of these inputs determines whether the postsynaptic cell will depolarize.

II. Classified according to postsynaptic target

A. **Axodendritic**. Most common

B. **Axosomatic**

C. **Axoaxonic**. Occur mostly at presynaptic terminals

D. **Neuromuscular junction**

III. Structure of the synapse ***(images)***

A. **Presynaptic component**

1. Distal end of the axon branches, each branch terminating in a swelling or button called the **terminal bouton.**

2. Boutons with neurotransmitter-containing *synaptic vesicles* and numerous mitochondria.

B. **Synaptic gap/cleft**. Separation (20-30 nm) between pre- and postsynaptic cells.

C. **Postsynaptic component**

1. Formed by the membrane of the postsynaptic neuron or muscle cell and contains receptors for neurotransmitters

2. Membrane shows a **postsynaptic density** or thickening on its cytoplasmic side.

D. **Bouton en passant**. "Bouton-like" swellings along the length of an axon, allow a single axon to contact many distant cells. Common in smooth muscle innervation.

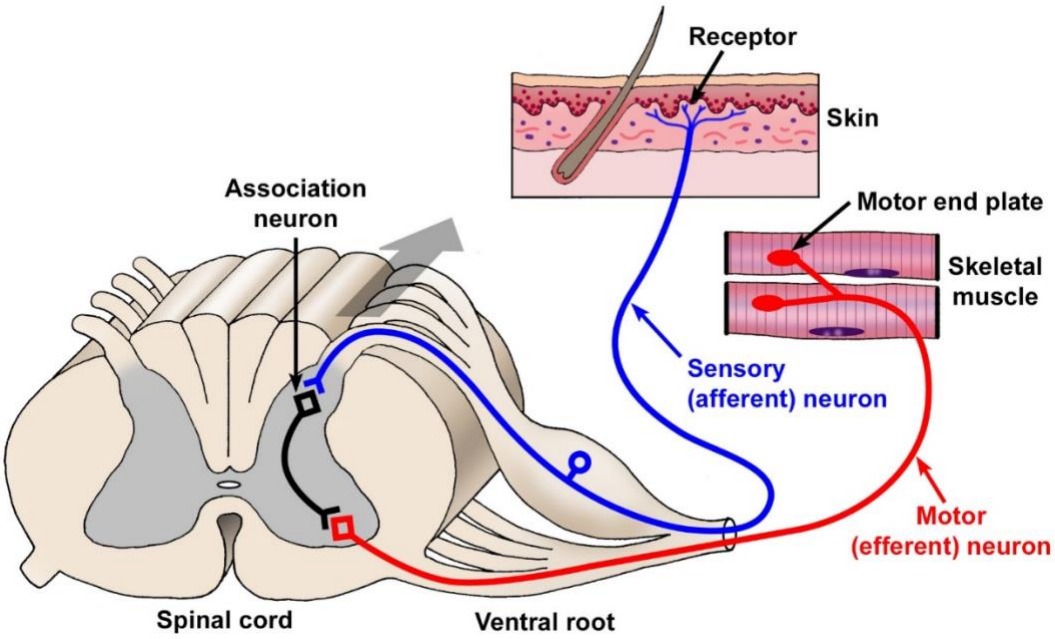


FIGURE 8.2. The reflex arc.

THE REFLEX ARC

I. The reflex arc is the simplest neuronal circuit and includes each of the elements discussed above. These circuits provide rapid, stereotyped reactions to help maintain homeostasis. To begin the reflex, a pseudounipolar, sensory neuron is activated by a receptor. The axon carries an afferent signal from the skin into the spinal cord where it synapses on a multipolar association neuron or interneuron. The interneuron signals a multipolar, motor neuron whose axon then carries an efferent signal to skeletal muscle to initiate contraction.

SUPPORTIVE CELLS

I. Supporting cells of the CNS (neuroglial cells) ***(images)***

A. **Astrocytes**

1. Stellate morphology
2. Types
    a. **Fibrous astrocytes** in white matter
    b. **Protoplasmic astrocytes** in gray matter
3. Functions
    a. Physical support
    b. Transport nutrients
    c. Maintain ionic homeostasis
    d. Take up neurotransmitters
    e. Form glial scars (gliosis)

B. **Oligodendrocytes**

1. Present in white and gray matter
2. **Interfascicular oligodendrocytes** are located in the white matter of the CNS, where they produce the myelin sheath.
3. **Perineuronal (satellite) oligodendrocytes** are located in regions of grey matter near neuronal cell bodies

C. **Ependymal cells**. Line ventricles, ciliated.

D. **Microglia**

1. Not a true neuroglial cell; derived from the yolk sac, whereas neuroglial cells, as well as neurons, are derived from ectoderm
2. Highly phagocytic cells
3. Provide immune surveillance and produce immunomodulatory compounds

II. Supporting cells of the PNS. **Schwann cells *(images)***

A. **Satellite Schwann cells** surround cell bodies in ganglia

B. **Ensheathing Schwann cells**

1. Surround unmyelinated axons. Numerous axons indent the Schwann cell cytoplasm and, therefore, are surrounded by a single plasma membrane.

2. Produce the myelin sheath around axons

MYELIN SHEATH *(images)*

I. The **myelin sheath** is formed by the plasma membrane of supporting cells wrapping around the axon. The sheath consists of multilamellar, lipid-rich segments produced by Schwann cells in the PNS and oligodendrocytes in the CNS.

II. Functions

A. Increases speed of conduction *(***saltatory conduction***)*

B. Insulates the axon

III. Similar structure in CNS and PNS with some differences in protein composition

IV. Organization

A. **Internode***.* Single myelin segment

B. **Paranode***.* Ends of each internode where they attach to the axon

C. **Node of Ranvier***.* Specialized region of the axon between myelin internodes where depolarization occurs

V. In the PNS, each Schwann cell associates with only one axon and forms a single internode of myelin.

VI. In the CNS, each oligodendrocyte associates with many axons (i.e. each oligodendrocyte forms multiple internodes on different axons).

CONNECTIVE TISSUE INVESTMENTS OF NERVOUS TISSUE

I. Peripheral nervous system ***(images)***

A. **Endoneurium***.* Delicate connective tissue surrounding Schwann cells;

includes the basal lamina secreted by Schwann cells as well as reticular fibers

B. **Perineurium**. Dense tissue surrounding groups of axons and their surrounding Schwann cells, forming fascicles; forms the blood-nerve barrier

C. **Epineurium**. Dense connective tissue surrounding fascicles and the entire nerve

II. Central nervous system (**meninges**)

A. **Pia mater**

1. Thin membrane lying directly on the surface of the brain and spinal cord

2. Accompanies larger blood vessels into the brain and spinal cord

B. **Arachnoid membrane**

1. Separated from pia mater by connective tissue trabeculae

2. Encloses the **subarachnoid space**, which contains blood vessels and the **cerebrospinal fluid (CSF)** produced by the cells of the choroid plexus

3. Together with pia mater, constitute the **leptomeninges**; inflammation of these membranes produces meningitis

C. **Dura mater**

1. Outermost of the meninges

2. Dense connective tissue that includes the periosteum of the skull

CHAPTER 10

CARDIOVASCULAR SYSTEM

GENERAL CONCEPTS

I. Continuous tubular system for transporting blood, carrying oxygen, carbon dioxide, hormones, nutrients, and wastes

II. Components of the circulatory system

A. **Heart**. Highly modified, muscular blood vessel specialized for pumping the blood. Composed of two atria and two ventricles.

B. **Closed circuit of vessels**. The vessels are listed below in the order that blood would follow as it leaves the heart.

1. **Elastic arteries** *(e.g.,* aorta and pulmonary arteries)

2. **Muscular arteries** (remaining named arteries)

3. **Small arteries and arterioles**

4. **Capillaries**

5. **Venules and small veins**

6. **Medium veins** (most named veins)

7. **Large veins** *(e.g.,* venae cavae, return blood to the heart)

III. Circuitries of the circulatory system

A. **Pulmonary circulation**

1. Circuit of blood between the heart and lungs

2. Blood leaves the right ventricle of the heart through the **pulmonary arteries** and proceeds through a series of smaller arteries to supply **pulmonary capillaries** in the lungs. Blood returns through a series of increasingly larger veins to the **pulmonary veins** to the left atrium.

3. Functions for exchange of carbon dioxide and oxygen between the blood and atmosphere

B. **Systemic circulation**

1. Circuit that distributes blood from the heart to the body tissues

2. Blood leaves the left ventricle of the heart through the **aorta** and proceeds through a series of smaller arteries to supply **systemic capillaries** throughout the body. Blood returns through a series of increasingly larger veins via the **superior and inferior venae cavae** to the right atrium.

3. Functions for exchange of carbon dioxide and oxygen, and nutrients and metabolic wastes between the blood and tissues; distribution of hormones.

C. **Lymphatic circulation**. Consists of a system of blind-ended lymph vessels positioned throughout the body, which return tissue fluid to the venous circulation.

BASIC STRUCTURAL ORGANIZATION *(images)*

I. The walls of the entire cardiovascular system, consists of three concentric layers or tunics that are continuous between both the heart and vessels. The constituents and thickness of these layers vary depending on the mechanical and metabolic functions of the vessel.

II. **Inner tunic**

A. In the heart, this layer is called the **endocardium**; in vessels, it is termed the **tunica intima**.

B. Composition

1. Simple squamous epithelium ***(endothelium)***

2. Varying amounts and types of connective tissue

3. In the largest vessels, longitudinally oriented smooth muscle may be present in the connective tissue layer.

III. **Middle tunic**

A. In the heart this layer is composed of cardiac muscle and is called the **myocardium**.

B. In vessels this layer is composed of circularly oriented smooth muscle or smooth muscle plus connective tissue and is called the **tunica media**.

IV. **Outer tunic**

A. In the heart, this layer consists of a serous membrane, called the **epicardiuim (visceral pericardium)** composed of connective tissue covered with a simple squamous epithelium (mesothelium).

B. In vessels, this layer is called the **tunica adventitia** and is composed of connective tissue; variable amount of longitudinally arranged smooth muscle is present in this layer in the largest veins.

C. Possesses blood vessels that supply the wall of the heart or larger blood vessels

1. **Coronary blood vessels**. Supply the heart wall

2. **Vasa vasorum**. Consists of a system of small blood vessels that supply the outer wall of larger vessels

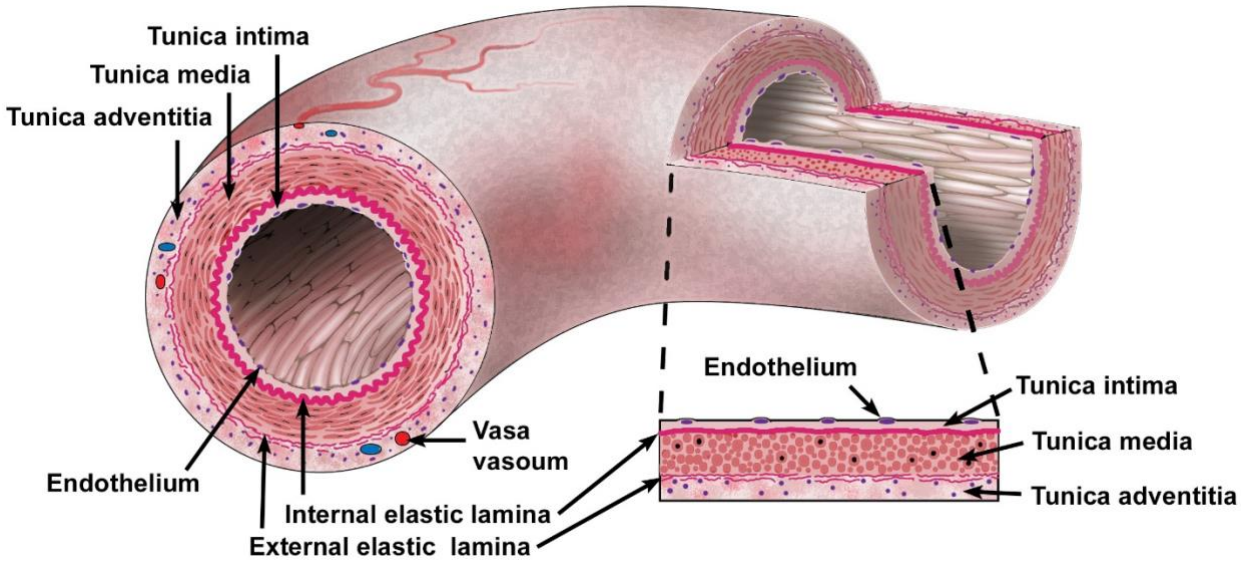


FIGURE 10.1. Structure of a muscular artery.

ARTERIES *(images)*

I. General considerations

A. Carry blood away from the heart and toward capillary beds

B. Have thicker walls and smaller lumens than veins of similar size

C. Tunica media is the predominate tunic.

D. Cross-sectional outlines are more circular in arteries than in veins.

II. Types (Only features distinct to each type and different from the Basic Structural Organization are presented)

A. **Elastic (large) arteries (aorta, pulmonary arteries)**

1. **Internal elastic lamina** in the tunica intima adjacent to the tunica media, is present but difficult to distinguish from the elastic tissue of the tunica media.

2. Tunica media is composed of fenestrated sheets of elastic tissue **(elastic lamellae)** and smooth muscle

3. Passively maintain blood pressure by distension and recoil of the elastic sheets

B. **Muscular (medium, distributing)** arteries

1. **Internal elastic lamina**. Prominent, single, fenestrated, elastic sheet located at its border with the tunica media.

2. Tunica media is composed of smooth muscle.

3. **External elastic laminae**. Consists of fenestrated elastic sheets at the junction of the tunica media and tunica adventitia.

4. Regulate blood pressure and blood distribution by contraction and relaxation of smooth muscle in the tunica media

C. **Small arteries and arterioles**

1. Less than 200 microns in diameter

2. Small arteries have an internal elastic lamina and up to eight layers of smooth muscle in the tunica media.

3. Arterioles usually lack an internal elastic lamina and have one to two layers of smooth muscle in the tunica media.

4. Arterioles are the vessels that regulate blood pressure and deliver blood under low pressure to capillaries.

CAPILLARIES

I. General considerations

A. Site of exchange of metabolites, wastes and gases between the vascular lumen and extravascular tissue.

B. Lumen is approximately 8 microns in diameter, thus only large enough for RBCs to move through in a single row.

C. Composed of the endothelium (simple squamous epithelium) and its underlying basal lamina

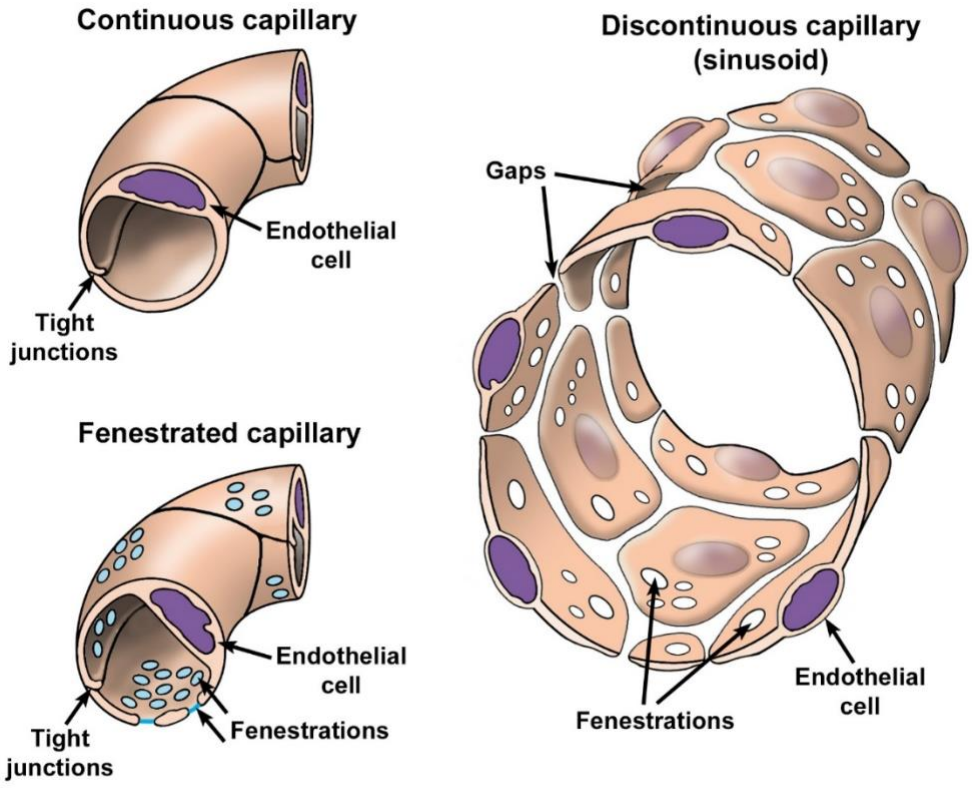


Figure 10.2. Types of capillaries

II. Types ***(images)***

A. **Continuous capillaries**

1. Most common

2. Endothelium is continuous (i.e., has no pores)

B. **Fenestrated capillaries**

1. Endothelium contains pores that may or may not be spanned by a **diaphragm**. If present, the diaphragm is thinner than two apposed

plasma membranes.

2. Pores with diaphragms are common in capillaries in the endocrine organs and portions of the digestive tract. Pores lacking diaphragms are uniquely present in the glomerular capillaries of the kidney.

3. Pores facilitate diffusion across the endothelium

C. **Discontinuous capillaries (sinusoids)**

1. Larger diameter and slower blood flow than in other capillaries

2. Endothelium has large pores that are not closed by a diaphragm.

3. Gaps are present between adjacent endothelial cells.

4. Partial or no basal lamina present.

5. Prominent in spleen and liver

VEINS *(images)*

I. General considerations

A. Return blood from capillary beds to the heart

B. Have thinner walls, larger lumens and more irregular cross-sectional outlines than arteries of similar size.

C. Tunica adventitia is the predominate tunic.

D. Larger veins possess **valves**, that are extensions of the tunica intima that serve to prevent back-flow of blood.

II. Types (Only features distinct to each type and different from the Basic Structural Organization are presented)

A. **Venules and small veins**

1. Tunica media is absent in venules. Smooth muscle fibers appear in the tunica media as venules progress to small veins.

2. **High endothelial venules***.* Venules in which the endothelium is simple cuboidal; facilitate movement of cells from the blood into the surrounding tissues (diapedesis). This type of venule is found in many of the lymphatic tissues.

B. **Medium veins**. Tunica media is composed of connective tissue and smooth muscle, with the latter increasing to form a more definitive and continuous portion as the vein increases in size. Most named veins are in this category.

C. **Large veins**, includes superior and inferior venae cavae; have well-developed, longitudinally oriented smooth muscle in the tunica adventitia in addition to the circularly arranged smooth muscle in the tunica media.

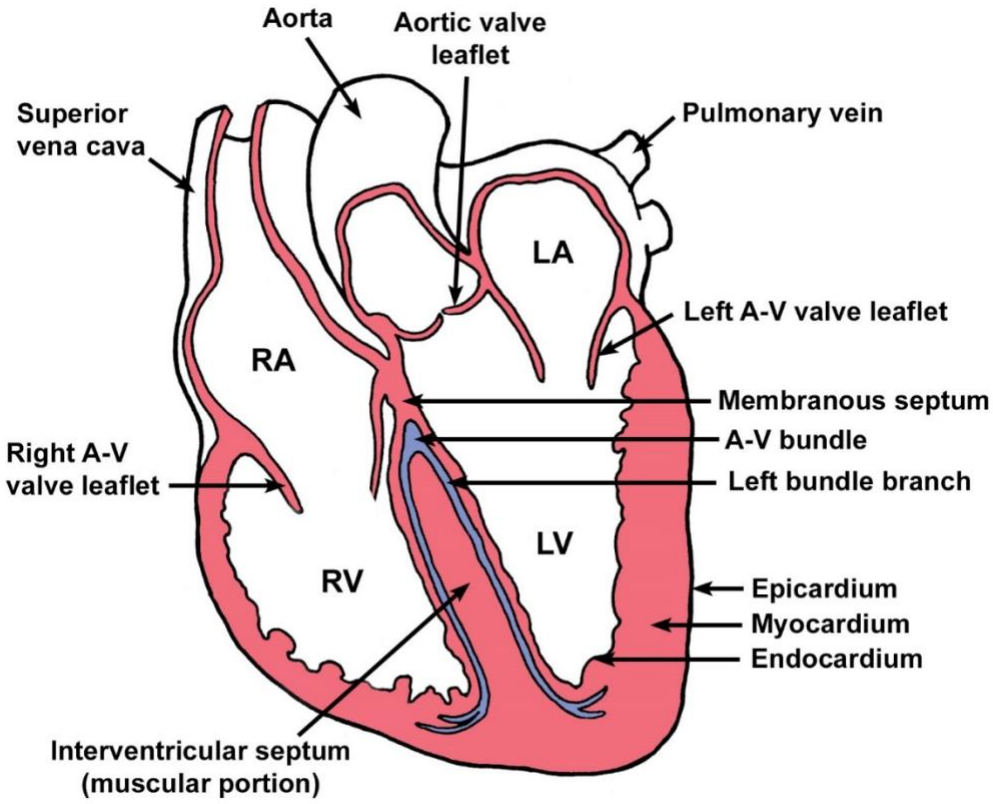


FIGURE 10.3. Diagram of a frontal section of the heart (RA, right atrium; LA, left atrium; RV, right ventricle; LV, left ventricle)

HEART *(images)*

I. Develops by a vessel folding back on itself to produce four chambers in the adult. Two upper chambers, **atria (singular, atrium)**, receive blood from the body and lungs; two **ventricles** pump blood out of the heart.

II. Tunics

A. **Endocardium**

1. Homologous to the tunica intima of vessels

2. Consists of an endothelium (simple squamous epithelium) plus underlying connective tissue of varying thickness. Smooth muscle may be present in the connective tissue layer.

3. **Cardiac valves**. Folds of the endocardium

    a. **Semilunar valves** at the bases of the aortic and pulmonary trunks prevent backflow of blood into the heart.

    b. **Atrioventricular valves (bicuspid and tricuspid)** prevent backflow of blood from the ventricles into the atria.

B. **Myocardium**

1. Composed of cardiac muscle

2. Fibers insert on components of the cardiac skeleton.

3. Thickest layer of the heart

4. Variation in thickness depends on the function of each chamber; thicker in ventricles than atria and thicker in left ventricle than right ventricle

C. **Epicardium (visceral pericardium)**

1. Serous membrane on the surface of the myocardium

2. Consists of a simple squamous epithelium and a loose connective tissue, with adipocytes, adjacent to the myocardium.

3. Coronary blood vessels are located in the connective tissue.

III. **Cardiac skeleton**. Thickened regions of dense connective tissue that provide support for heart valves and serve as insertion of cardiac muscle fibers

A. **Annuli fibrosi** are connective tissue rings that surround and stabilize each valve.

B. **Fibrous trigones** regions of connective tissue that connect the annuli fibrosis

C. **Membranous septum** is a connective tissue partition forming the upper portion of the interventricular septum; this connective tissue also separates the left ventricle from the right atrium.

IV. Impulse conducting system. Formed of specialized cardiac muscle fibers that initiate and coordinate the contraction of the heart

A. **Sinoatrial (SA) node** in the right atrium is the electrical **pacemaker** that initiates the impuse.

B. Fibers spread the impulse throughout the atria as well as transferring it to the atrioventricular node.

C. The **atrioventricular (AV) node** is located in the **interatrial septum**.

D. An **atrioventricular bundle** extends from the AV node in the **membranous septum** and bifurcates into right and left **bundle branches** that lie beneath the endocardium on both sides of the **interventricular septum**.

E. **Purkinje fibers**, modified, enlarged cardiac muscle fibers leave the bundle branches to innervate the myocardium.

CHAPTER 11

SKIN (INTEGUMENTARY SYSTEM)

FUNCTIONS OF SKIN

I. Protection against physical abrasion, chemical irritants, pathogens, UV radiation, and desiccation

II. Thermoregulation

III. Reception of pressure and touch sensations

IV. Production of vitamin D

V. Excretion

COMPONENTS OF SKIN

I. **Epidermis**. Stratified squamous keratinized epithelium

II. **Dermis**. Composed of two layers of connective tissue containing blood vessels, nerves, sensory receptors, and sweat and sebaceous glands. Beneath the dermis is a layer of loose connective and adipose tissues that forms the superficial fascia of gross anatomy termed the **hypodermis (subcutis)**. This layer is considered along with the skin, though technically it is not part of the integument.

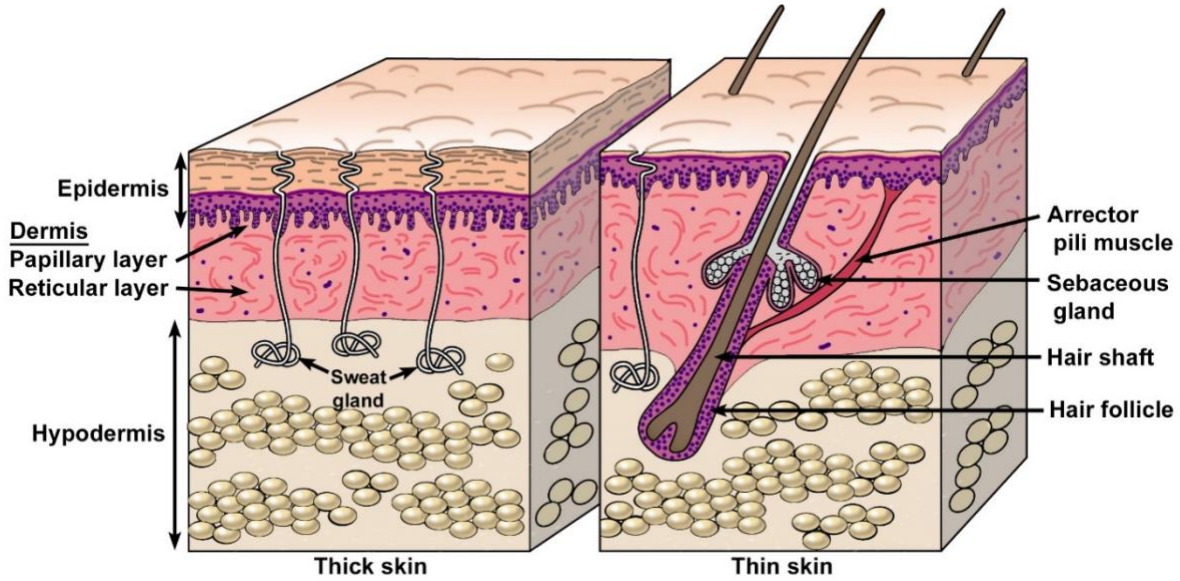


FIGURE 11.1. Structure of thin and thick skin.

CLASSIFICATION OF SKIN (Based on the thickness of the epidermis)

I. **Thin skin**

A. Covers entire body except palms and soles; 0.5 mm thick on the eyelid, 5 mm thick on the back and shoulders

B. Epidermis is thin, 0.075-0.15 mm thick, but the dermis varies from thin to very thick, depending on location.

C. Possesses hair with sebaceous glands

D. Sweat glands are present.

II. **Thick (glabrous) skin**

A. Located on palms of the hands and soles of the feet; 0.8-1.5 mm thick

B. Epidermis is 0.4-0.6 mm thick.

C. Hairless and, thus, possesses no sebaceous glands

D. Sweat glands are present.

EPIDERMIS *(images)*

I. Cell types

A. **Keratinocytes**. Keratinizing epidermal cells, major cell type in the epidermis

B. **Melanocytes**. Melanin pigment-producing cells

1. Present in stratum germinativum and stratum spinosum

2. Rounded cell bodies with clear cytoplasm. Numerous "dendrite-like" processes insinuate themselves between the keratinocytes

3. Synthesize **melanin**, a dark brown pigment that is packaged into **melanosomes** and injected into keratinocytes

4. Melanin caps the keratinocyte nucleus, reducing damage from solar radiation.

C. **Langerhans cells**. Macrophages that function in immunological skin reactions.

D. Merkel's cells. Touch receptors.

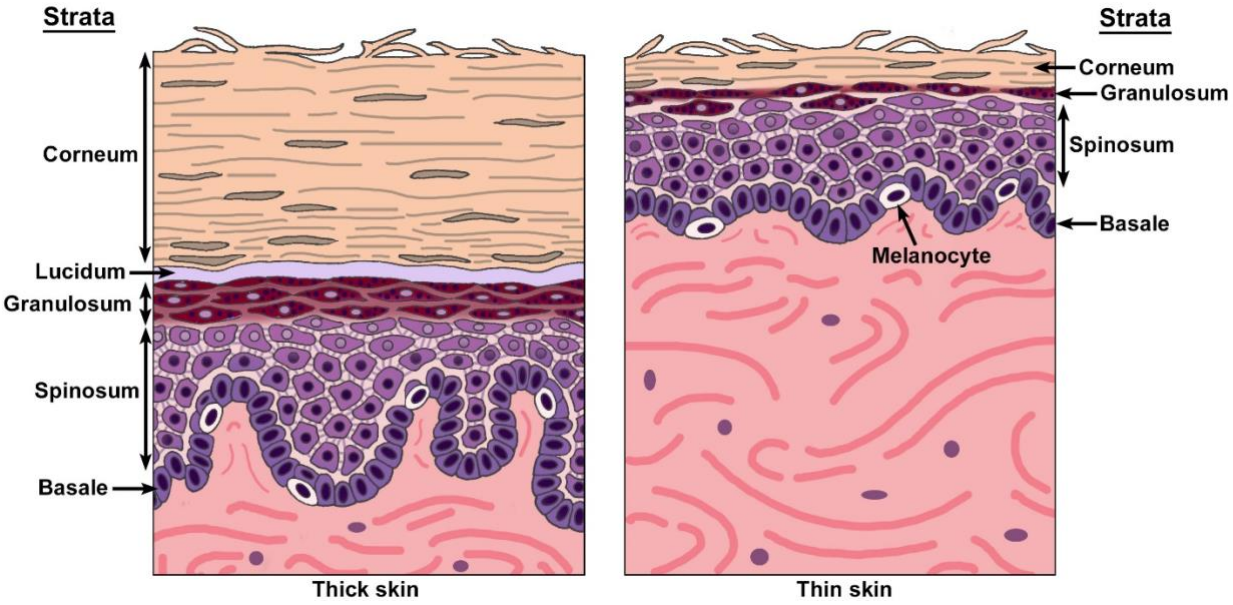


FIGURE 11.2. Comparison of epidermal layers in thick and thin skin.

II. Layers of the epidermis and keratinization

A. The epidermis is a stratified squamous, keratinized (dry) epithelium. It is continually renewed every 15-30 days. Rapid cell proliferation occurs primarily in the deepest layer (stratum germinativum) and daughter cells differentiate as they migrate toward the surface. This differentiation involves a process called keratinization, which results in a variably thick layer of nonliving cellular husks at the surface of the epidermis. All cells in the epidermis that undergo the keratinization process are called keratinocytes.

B. Layers of the epidermis

1. **Stratum basale (germinativum)**. A single layer of cuboidal to columnar shaped cells that rest on the basement membrane and undergo rapid cell proliferation. These cells contain intermediate filaments composed of keratin (tonofilaments).

2. **Stratum spinosum**. "Prickle-cell" or spiny cell layer; 3-10 cells thick. This layer is so-called because the cells are attached to one another by desmosomes, and the cellular shrinkage resulting from fixation produces the spine-like structures. These cells accumulate bundles of tonofilaments called tonofibrils.

3. **Stratum granulosum**: two to four cells thick; cells synthesize basophilic, **keratohyalin granules**, which associate with the tonofibrils. Cells also accumulate **lamellar bodies**, which contain a lipid material that is

secreted and serves as a sealant and penetration barrier between cells. Cells also begin to lose other organelles.

4. **Stratum lucidum**. A clear layer of non-nucleated, flattened cells that is only visible as a distinct layer in thick skin. In this region, the proteins contained in the keratohyalin granules mediate the aggregation of tonofibrils. This process occurs whether or not a distinct stratum lucidum is visible.

5. **Stratum corneum**. Variably thick layer of extremely flattened, cornified scales containing aggregated tonofibrils surrounded by a thickened plasma membrane. These cell remnants are sloughed off without damage to the underlying, living epidermal cells.

III. Epidermal-dermal junction

A. Scalloped margin at the interface of the epidermis and dermis, formed by interdigitations of:

1. **Epidermal pegs**. Downward projections of the epidermis

2. **Dermal papillae**. Upward, finger-like protrusion of connective tissue from the dermis

B. This junction strengthens the attachment of the epidermis to the underlying dermis.

DERMIS *(images)*

I. Composition

A. **Papillary layer**

1. Located immediately beneath the basement membrane of the epidermis, forming the dermal papillae

2. Thin layer composed of loose connective tissue

3. Contains small blood vessels, nerves, lymphatics, and the sensory receptors, Meissner's corpuscles

B. **Reticular layer**

1. Located between the papillary layer and the hypodermis

2. Thick layer composed of dense, irregular connective tissue

3. Contains larger nerves and blood vessels, glands, hair follicles, and the

sensory receptors, Pacinian corpuscles and Ruffini end organs

II. Vasculature of the dermis

A. **Papillary plexus** located in the dermal papillae

B. **Cutaneous plexus** located in the reticular layer of the dermis

C. **Arteriovenous anastomoses** allow shunting of blood between papillary and cutaneous plexuses for temperature regulation.

HYPODERMIS (SUBCUTIS)

I. Not technically part of the integument

II. Composed of loose connective tissue and adipose tissue, which can accumulate in large fatty deposits

III. Provides anchorage for skin to the underlying tissues

IV. May contain the bases of sweat glands and hair follicles

V. Many sensory receptors, especially Pacinian corpuscles, are present.

STRUCTURES ASSOCIATED WITH THE SKIN

I. Glands ***(images)***

A. **Sweat glands**

1. Simple, coiled tubular glands

2. Contain **myoepithelial cells**, which are specialized cells that contract to aid in the expulsion of the sweat

3. Types of sweat glands

a. **Merocrine or eccrine**. Located in all regions of the body except the axillary and anal regions; produce a watery secretion that empties onto the surface of the epidermis

b. **Apocrine**. Restricted to the axillary, areolar, and anal regions; much larger than eccrine sweat glands with a broader lumen. Produce a viscous secretion that empties into the hair follicle. Do not secrete by the apocrine mode, as once thought.

B. **Sebaceous glands**

1. Simple, branched acinar glands

2. Usually secrete into a hair follicle

3. Produce sebum, an oily secretory product, released by the holocrine mode of secretion

4. Absent from thick skin

II. **Hair follicles**

A. Invaginations of the epidermis

B. Consist of a **bulb** at the base of the follicle that is located in the hypodermis or in the deep layers of the dermis. **Internal and external sheaths** surround the growing **hair shaft** as it passes though the dermis and epidermis.

C. An **arrector pili** muscle attaches a hair follicle to the papillary layer of the dermis. Contraction provides elevation of the hair, forming "goose-bumps."

III. **Nails *(images)***

A. Keratinized epithelial cells on the dorsal surface of the fingers and toes

B. Consist of a **nail plate** that corresponds to the stratum corneum of the epidermis. This plate rests on the **nail bed**, consisting of cells corresponding to the stratum spinosum and stratum germinativum.

C. **Nail root** lies in an epidermal fold, whose stratum corneum forms the **eponychium (cuticle)**

D. **Nail matrix** lies beneath the nail root and is the germinative portion of the nail.

E. The **hyponychium**, a thickened epidermis, secures the nail at the fingertip

IV. Sensory structures ***(images)***

A. Nonencapsulated. **Free nerve endings** in the epidermis, responsive to touch, pressure, heat, cold, and pain

B. Encapsulated pressure receptors

1. **Meissner's corpuscle**

a. Located at the apex of a dermal papilla

b. Consists of a coil of **Schwann cells** around a nerve terminal

c. Responds to light touch

2. **Pacinian corpuscle**

   a. Located in the dermis and hypodermis

   b. Consists of concentric layers of **endoneurial cells** around a nerve terminal

   c. Responds to vibration and deep pressure

3. **Ruffini ending**

   a. Located in the dermis

   b. Consists of groups of nerve terminals surrounded by a thin connective tissue capsule

   c. Responds to touch and pressure

CHAPTER 12

DIGESTIVE SYSTEM
(Oral cavity, tubular tract and glands)

LIP *(images)*

I. Forms the anterior boundary of the **vestibule**, the space between the inner surfaces of the lips and cheeks and the outer surface of the teeth and gums

II. Regions

A. Exterior surface

1. Covered by **thin skin**

2. **Hair follicles** and **sebaceous glands** are present

B. **Vermilion zone**

1. Forms the red-colored portion of the lip

a. Covered by a thin, stratified squamous keratinized epithelium

b. Mucosa contains numerous, densely packed dermal papillae

c. Papillae allow blood vessels close access to the surface

2. Lacks hair follicles

C. Inner surface

1. Lined by **oral mucosa**, stratified squamous moist epithelium

2. **Minor salivary glands (labial glands)** in the submucosa secrete both mucous and serous products.

III. **Orbicularis oris muscle**

A. Skeletal muscle arranged as a sphincter around the mouth.

B. Forms the core of the lip.

ORAL CAVITY

COMPONENTS

I. **Vestibule**. Bounded anteriorly and laterally by the lips and cheeks; bounded medially by teeth and gingiva (gums).

II. **Oral cavity proper**. Bounded anteriorly and laterally by the lingual surfaces of the teeth and gingiva, superiorly by the hard and soft palate, inferiorly by the tongue and floor of the mouth, and posteriorly by the pillars of the fauces leading to the pharynx

ORAL MUCOSA *(images)*

I. **Oral mucosa**, the mucous membrane (mucosa) lining the oral cavity and vestibule, is continuous with external skin and with the mucous membrane of the pharynx.

II. Composition

A. Epithelium. Stratified squamous keratinized or nonkeratinized depending on location

B. Lamina propria

C. Muscularis mucosae is not present.

D. Although not part of the oral mucosa, a submucosa of dense connective tissue, containing the minor salivary glands, underlies much of the oral mucosa.

III. Regional variations, depending on function and location

A. **Masticatory mucosa**

1. Located where mucosa is exposed to forces of mastication, such as gingiva and hard palate

2. Composition

a. Stratified squamous epithelium, keratinized

i. **Orthokeratinized epithelium** resembles the epidermis of the skin with a fully keratinized stratum corneum and is located in areas of maximal trauma.

ii. **Parakeratinized epithelium** does not fully keratinize, retaining

pyknotic nuclei and organelles in the surface cells. This epithelium is found in areas of reduced trauma.

b. Underlying submucosa is lacking in some locations.

B. **Lining mucosa**

1. Located where mucosa is not exposed to forces of mastication (minimal trauma), such as lining of lips and cheeks, soft palate, alveolar mucosa, undersurface of tongue, and floor of mouth

2. Epithelium. Stratified squamous epithelium, nonkeratinized (moist)

C. **Specialized mucosa**

1. Named "specialized" due to the presence of **taste buds**

2. Located on the dorsum of the tongue where it forms **papillae**

3. Epithelium

a. Stratified squamous keratinized, modified to form **filiform papillae** that facilitate the movement of food posteriorly

b. Stratified squamous moist, covering **fungiform** and **circumvallate papillae**

TONGUE ***(images)***

I. The subdivisions of the **tongue** are based on embryologic origins: anterior two two-thirds (body) and posterior one-third (root) are separated by the sulcus terminalis.

II. Composition

A. **Mucosa**. Dorsum of the tongue is covered by a specialized oral mucosa, modified to form papillae. (See "Specialized mucosa" above.) The ventral surface of the tongue is covered by a lining mucosa

B. The **submucosa** possesses **minor salivary glands** that are mucus-secreting except for those associated with the circumvallate papillae, which are serous-secreting

III. **Papillae**. Each consists of a connective tissue core covered by a stratified squamous epithelium.

A. **Filiform**

1. Most numerous; cover body of tongue

2. Cone-shaped protrusions angled so that they aid in movement of food toward the pharynx

B. **Fungiform**

1. Less numerous than filiform but also located on anterior two-thirds of tongue

2. Mushroom shaped, possess taste buds on superior surface

C. **Circumvallate**

1. Eight to twelve papillae located just anterior to the sulcus terminalis

2. Mushroom shaped and surrounded by a narrow moat; lateral wall of each papilla possesses taste buds

3. **Serous glands of von Ebner** open into the base of the moat and flush the moat for reception of new tastes.

D. **Foliate**. Parallel folds on the posterolateral surface of the tongue; not well developed in humans

IV. **Taste buds** are onion-shaped structures embedded in the surface of the fungiform and circumvallate papillae. Taste buds contain taste-receptor cells that communicate with the surface of the papilla through a **taste pore**. Depolarization of the taste cells leads to the stimulation of gustatory nerve fibers and the discrimination of sweet, salty, bitter, and sour sensations.

V. **Intrinsic tongue muscles**. Skeletal muscle bundles are arranged in three separate planes, with connective tissue bands from the lamina propria separating the bundles and firmly anchoring the muscle to the mucous membrane.

TEETH *(images)*

I. Overview of the **teeth**

A. **Anatomic crown**. The portion of the tooth covered by enamel.

B. **Anatomic root**. The portion of the tooth covered by cementum.

C. **Cervix**. Region where enamel abuts cementum

D. **Pulp cavity** is the central core of a tooth and is divided into a pulp chamber in the crown and a root canal in the root. An apical foramen at the tip of the root allows passage of nerves and blood vessels into and out of the pulp cavity.

E. **Gingiva**. Oral mucosa (masticatory) encircling the cervical region of the tooth and providing support for the tooth

II. Components

A. **Enamel** is the hardest tissue in the body, consisting of a mineralized tissue that is 96% hydroxyapatite. Enamel covers the anatomic crown of the tooth. During tooth development, enamel deposition by **ameloblasts** begins on the surface of dentin and progresses away from this **dentinoenamel junction**. No additional enamel can be formed after the tooth erupts, as the ameloblasts die on exposure to the oral cavity.

B. **Dentin**

1. Comprises the bulk of the tooth, underlying both enamel and cementum; dentin is a connective tissue that is 70% mineralized with hydroxyapatite.

2. Dentin is formed continuously throughout life by **odontoblasts** whose cell bodies line the pulp cavity.

3. Odontoblast processes extend through the dentin in S-shaped dentinal tubules radiating from the odontoblasts toward the **dentinoenamel** or **dentinocemental junctions**.

C. **Cementum**, a connective tissue mineralized with 50% hydroxyapatite, covers the anatomic root of the tooth. Cementum is formed continuously throughout life by activity of **cementoblasts** lying on the surface of the root at the interface of the cementum with the periodontal ligament.

D. The **pulp cavity** is lined by odontoblasts and filled with loose connective tissue, blood vessels, nerves, and lymphatics.

E. The **periodontal ligament**, collagen fiber bundles interconnecting cementum with the surrounding alveolar bone, suspends and supports each tooth in its alveolar socket.

MAJOR SALIVARY GLANDS *(images)*

I. Overview

A. All major salivary glands are compound, exocrine glands, and all open into the oral cavity.

B. Functions

1. Produce saliva to wet, lubricate, and buffer the oral cavity and its contents

2. Produce amylase for the initial digestion of carbohydrates

3. Produce lysozyme to control bacteria in the oral cavity

II. Major cell types

A. **Serous cells**

1. Synthesize, store, and release a thin, protein-rich secretion containing digestive enzymes, primarily amylase

2. Are pyramidal in shape and possess all organelles necessary for protein production and secretion (e.g., basal rough endoplasmic reticulum, Golgi, and apical secretory granules)

3. Are arranged into either:

a. **Acini** (singular, **acinus***)* or **alveoli** (singular, **alveolus***).* Flask-shaped sacs with tiny lumens

b. **Serous demilunes***.* Half moon–shaped caps positioned over the ends of mucous tubules

B. **Mucous cells**

1. Synthesize, store, and release mucus, a viscous, thick, glycoprotein secretion that protects and lubricates epithelia

2. Have flattened nuclei that are located at the bases of the cells along with the rough endoplasmic reticulum. Abundant **mucigen droplets** are located in the apex of each cell, giving it a frothy, vacuolated appearance.

3. Are organized in test tube–shaped **tubules** with relatively wide lumens

C. **Myoepithelial cells** are stellate-shaped epithelial cells with contractile functions that lie between the secretory or duct cells and the basement membrane. These cells contract to aid in movement of the secretory product.

III. Duct system conducts secretions to oral cavity.

A. Ducts are more numerous with serous acini than with mucous tubules because the tubules can act as their own ducts.

1. **Intralobular ducts**

    a. **Intercalated ducts** exit from secretory acini and are smaller in diameter than the acini they drain. These ducts are lined by simple cuboidal epithelia.

    b. **Striated ducts** continue from intercalated ducts and are larger in diameter than the secretory units they drain. They are lined by simple columnar epithelia. Numerous mitochondria and infoldings of the plasma membrane in the basal region of the cells give the duct a striated periphery. Striated ducts alter the content and concentration of the saliva.

2. **Interlobular ducts** form by the anastomosis of striated ducts and are located in the connective septa between lobules. Interlobular ducts are lined with simple columnar to stratified columnar epithelia.

3. The **main excretory duct(s)** is formed by the union of interlobular ducts. An excretory duct (s) is lined by a stratified epithelium that becomes stratified squamous moist just prior to its junction with the epithelium of the oral cavity.

IV. Major salivary glands

A. **Parotid glands**

1. Compound acinar glands producing only serous products; their secretions account for 25% of the saliva

2. Possess the most highly developed duct system of the major salivary glands

B. **Submandibular glands**

1. Compound tubulo-acinar glands producing both serous and mucous products, although serous acini predominate. Their secretions account for 70% of the saliva.

2. Serous cells are present as both acini and **serous demilunes**.

C. **Sublingual glands** secrete approximately 5% of the saliva. These are compound tubulo-acinar glands, producing both mucous and serous products, although mucous tubules predominate

TUBULAR DIGESTIVE SYSTEM

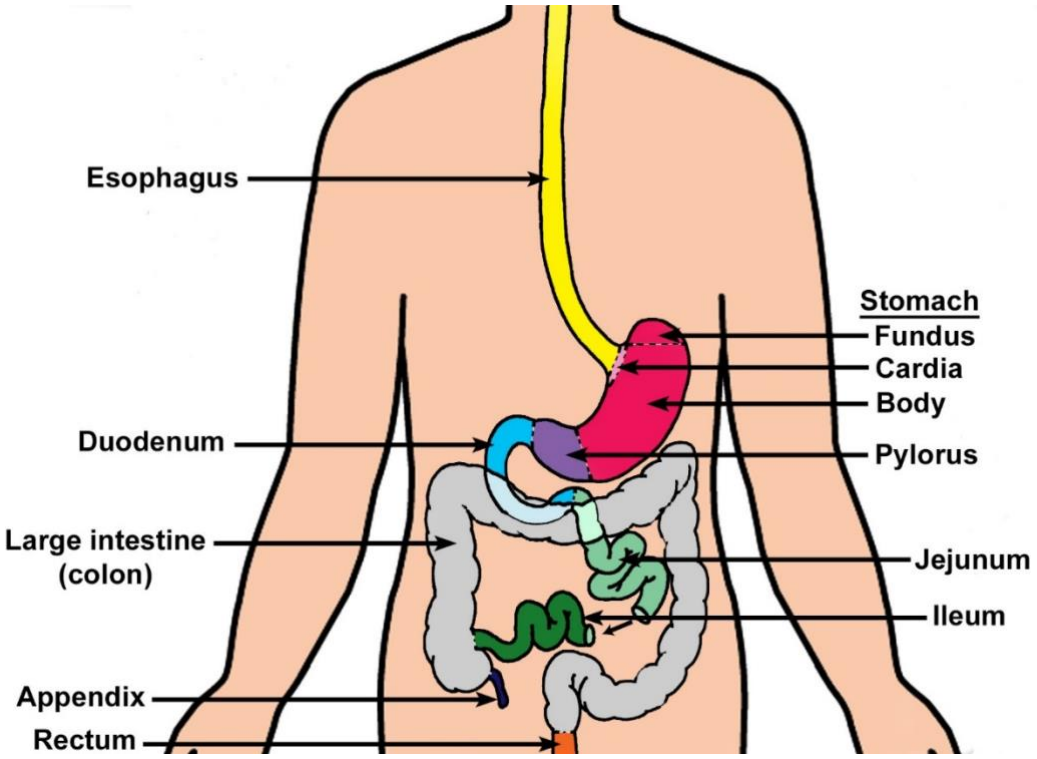


FIGURE 12.1. Organs comprising the tubular digestive tract.

COMPONENTS

I. Pharynx

II. Esophagus

III. Stomach

IV. Small intestine

V. Large intestine

VI. Anus

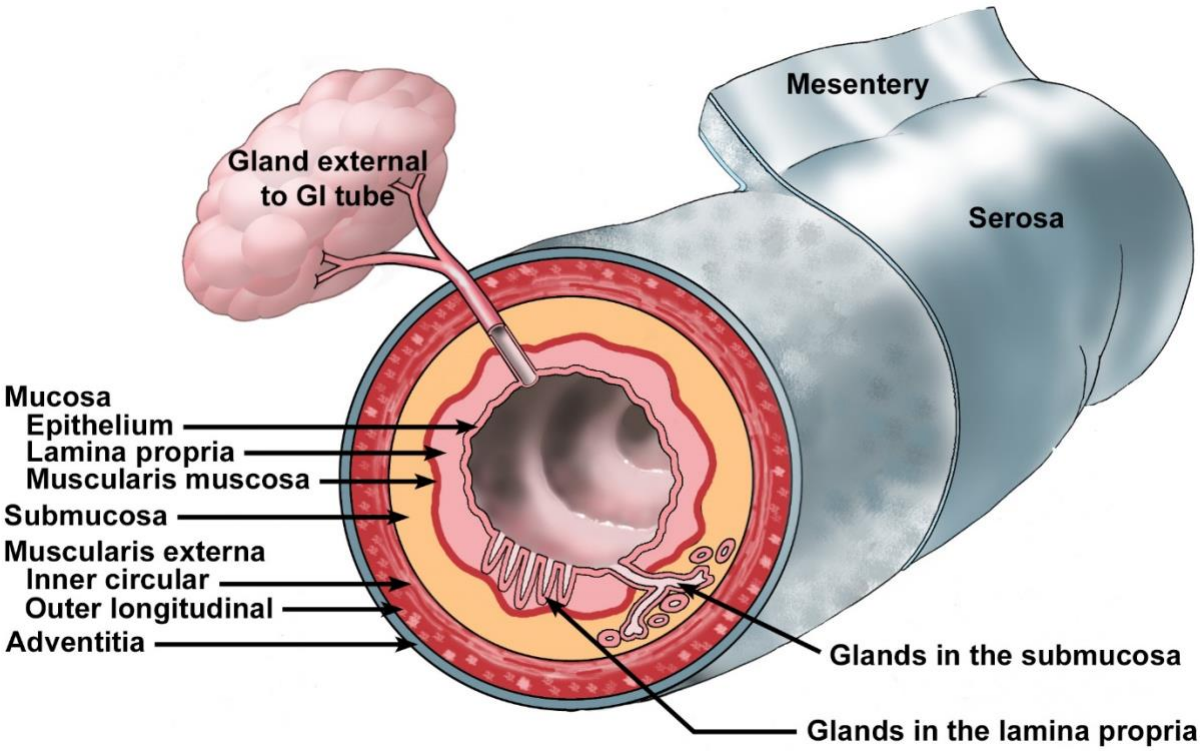


FIGURE 12.2. Overview of the layers and components of the tubular digestive tract.

BASIC HISTOLOGICAL ORGANIZATION

I. Layers

A. **Mucosa (mucous membrane)**. Innermost layer facing the lumen

1. **Epithelium**. Either a stratified squamous moist or a simple columnar epithelium

2. **Lamina propria**. Loose connective tissue; usually possesses digestive glands

3. **Muscularis mucosae** of smooth muscle is usually present.

B. **Submucosa**. Denser connective tissue than the lamina propria. The submucosa possesses **Meissner's nerve plexus** that supplies innervation to the muscularis mucosae and to digestive glands in the mucosa and submucosa. The submucosa possesses glands in the esophagus and duodenum.

C. **Muscularis externa** of smooth muscle is usually arranged into inner circular and outer longitudinal layers. **Auerbach's nerve plexus** is located between the two muscle layers and provides innervation to this smooth muscle.

D. **Serosa** (serous membrane) is present if the organ protrudes into the peritoneal cavity, or an **adventitia** (only the connective tissue portion of the serosa) is present if the organ is retroperitoneal.

II. Glands

A. Exocrine glands, aiding in digestion and/or lubrication, are located in:

1. Epithelium (e.g., goblet cells throughout the intestines)

2. Lamina propria (e.g., gastric glands)

3. Submucosa (e.g., Brunner's glands in the duodenum)

4. Glands located external to the digestive tract that open into the system (e.g., liver and pancreas)

B. Endocrine and paracrine cells, belonging to the diffuse **neuroendocrine system (DNES)**, are located throughout the mucosa of the gastrointestinal tract, influencing the secretion of glands and the motility of the gut.

VARIATIONS THAT DISTINGUISH EACH ORGAN FROM THE BASIC ORGANIZATIONAL PLAN

I. **Esophagus *(images)***

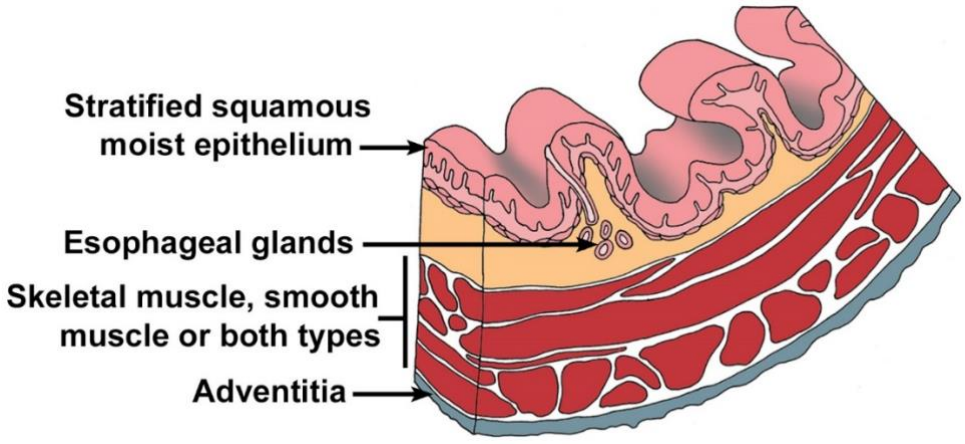


FIGURE 12.3. Cross-section of the esophagus.

A. Epithelium. **Stratified squamous nonkeratinized epithelium**

B. Lamina propria possesses **esophageal cardiac glands** that resemble the mucus-secreting glands of the cardiac portion of the stomach. These glands are particularly prominent near the junction of the esophagus with the stomach and are sometimes located in the beginning of the esophagus.

C. Submucosa has mucus-secreting, **esophageal glands proper**.

D. Muscularis externa is composed of **striated muscle** in the upper portion of the esophagus, skeletal, and smooth muscle in the middle portion, and smooth muscle in the lower portion.

E. Adventitia. Composed of loose connective tissue.

II. Stomach *(images)*

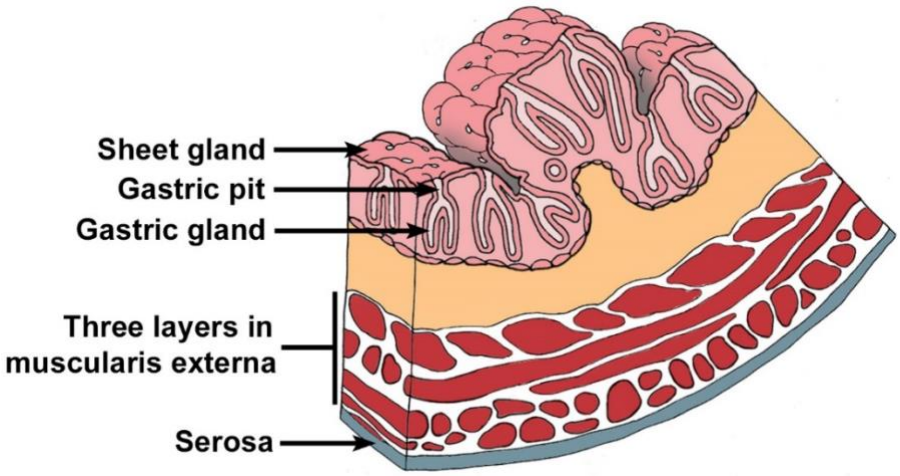


FIGURE 12.4. Cross-section of the stomach.

A. Structures present throughout the stomach

1. Surface epithelium

   a. Simple columnar epithelium facing the lumen is modified so that all cells secrete mucus, forming a **sheet gland** that protects the stomach from its acidic environment.

   b. **Gastric pit**. A channel formed by the invagination of the surface epithelium into the underlying lamina propria; connects the sheet gland with the gastric glands. The length of the gastric pit varies with each stomach region.

2. **Gastric glands**

   a. Simple, branched tubular glands begin at a gastric pit and extend

through the lamina propria to the muscularis mucosae.

b. The region of the gland that attaches to the gastric pit is called the **neck region**; the base region of the gland is located adjacent to the muscularis mucosae.

c. Secretory cells in these glands vary in each region of the stomach.

3. Muscularis externa. Subdivisions of this smooth muscle layer frequently interdigitate, making it difficult to distinguish one layer from another.

a. Internal oblique layer

b. Middle circular layer that is modified in the pyloric region to form the pyloric sphincter

c. Outer longitudinal layer is separated from the inner circular layer by Auerbach's plexus, nerve fibers from the autonomic nervous system that supply

4. Serosa

5. **Rugae**. Longitudinal folds of the mucosa and submucosa in the undistended stomach allow for expansion.

B. Variations specific to the **cardiac region** (narrow region adjacent to the esophagus)

1. Abrupt transition of epithelium from stratified squamous moist of the esophagus to a sheet gland lining the cardiac stomach

2. Length of gastric pits is about equal to the length of cardiac glands

3. **Cardiac glands** primarily secrete mucus, although other products are also produced. Glands are frequently coiled.

4. Cardiac glands of the stomach extend into the lower esophagus, forming the esophageal cardiac glands.

C. Variations specific to the **fundic and body regions** (Glands in both regions are called fundic glands.)

1. **Fundic glands** are about twice as long as their gastric pits.

2. Cell types present in fundic glands:

a. **Stem cells** replenish both the surface epithelial cells and cells of the glands. Stem cells are located in the neck region.

b. **Mucous neck cells** are irregular in shape and stain basophilically. They secrete mucus and are located in the neck region.

c. **Parietal cells** are large, spherical, eosinophilic cells that secrete hydrogen and chloride ions and gastric intrinsic factor. They possess numerous mitochondria. An umbrella-shaped canaliculus indents the luminal surface, increasing surface area. Although present throughout the gland, parietal cells are more numerous in the upper regions.

d. **Chief or zymogen cells**, typical protein-producing cells, predominate in the bases; stain blue with hematoxylin and secrete pepsinogen.

e. **Enteroendocrine cells** (part of the diffuse neuroendocrine system, DNES) are located on the basement membrane and do not usually reach the lumen of the gland. This population of cells secretes a variety of hormones with endocrine and paracrine influences on digestive activity. Secretory granules cluster toward the basement membrane for their subsequent release into the lamina propria. Most common at the bases of the glands.

D. Variations specific to the **pyloric region**

1. Pits are longer in pylorus than in the cardiac region.

2. **Pyloric glands**, not as coiled as in the cardiac region; primarily secrete mucus.

3. Enteroendocrine cells are also present here.

4. Circular layer of muscularis externa is greatly thickened to form the **pyloric sphincter**.

III. Small intestine *(images)*

A. Subdivided into **duodenum**, **jejunum**, and **ileum**

B. Common features of the small intestine.

1. Structures that increase the surface area of the small intestine

a. **Microvilli**. Increase surface area of absorptive cells and, collectively, form a brush or striated border

b. **Villi**. Finger-like protrusions of the lamina propria and overlying epithelium into the lumen

i. Villi assume different shapes in each of the three intestinal subdivisions.

ii. A **lacteal** (blind-ending lymphatic capillary) is located in the center of each villus to absorb digested fat.

iii. Individual smooth muscle cells lie parallel to the long axis of each villus, "milking" the lacteal contents to the periphery.

c. **Plicae circulares**. Permanent circular folds formed by an up-welling of the submucosa and its overlying mucosa into the lumen. Villi protrude from the plicae.

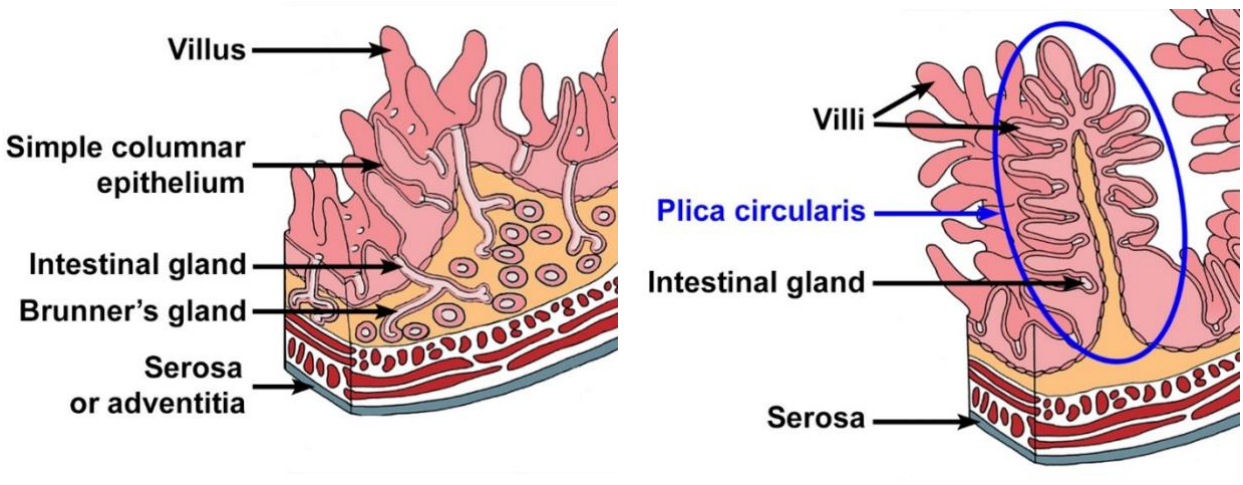


FIGURE 12.5. Longitudinal section through the duodenum (left) and the jejunum/ ileum (right). Note the orientation of the layers of muscularis externa when sectioned longitudinally.

2. Mucosal epithelium is composed of:

a. **Absorptive cells (enterocytes)**, forming a simple columnar epithelium with microvilli, absorb digested food

b. **Goblet cells** (unicellular glands) are interspersed among absorptive cells and secrete mucus. These cells increase in number from duodenum to rectum.

3. **Intestinal glands (crypts of Lieberkuhn)** are simple tubular glands that begin at the bases of the villi in the mucosa and extend through the lamina propria to the muscularis mucosae. Possess:

a. Absorptive cells

b. Goblet cells

c. **Paneth cells** possess large, eosinophilic granules whose contents, e.g, lysozyme, digest bacterial cell walls.

d. **Enteroendocrine cells**

4. Muscularis externa of inner circular and outer longitudinal layers with an intervening Auerbach's nerve plexus

5. Serosa covers all of small intestine except for the beginning of the duodenum, which is retroperitoneal and possesses an adventitia.

C. Variations specific to the intestinal subdivisions

1. **Brunner's glands** in the submucosa are present only in the duodenum. These compound tubular glands open into the bases of the intestinal glands and secrete an alkaline mucus to neutralize the acidity of the stomach contents.

2. **Peyer's patches** are clusters of 10-200 lymphoid nodules located primarily in the lamina propria of the ileum. Each cluster is positioned on the side of the intestine away from the mesentery and forms a bulge that may protrude into the lumen as well as into the submucosa.

IV. Large intestine (colon) *(images)*

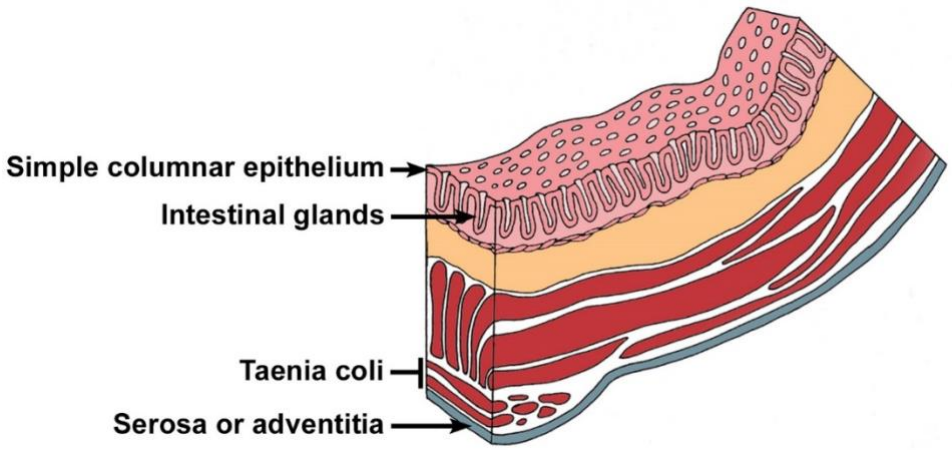


FIGURE 12.6. Cross-section of the large intestine.

A. Layers and structures forming the wall of the large intestine.

1. Mucosal epithelium:

a. Absorptive cells form a simple columnar epithelium with microvilli.

b. Goblet cells increase in number toward the rectum and provide lubrication.

c. A reduced number of enteroendocrine cells is present.

2. Intestinal glands (crypts of Lieberkuhn) are very straight in the large intestine.

3. No villi or plicae circulares are present in the large intestine.

4. Muscularis externa

a. Inner circular layer is complete around the circumference of the tube

b. Outer longitudinal layer is segregated into three longitudinal bands, the **taeniae coli**, that are placed equidistantly around the tube. The contraction of the taenia produces permanent sacculations in the large intestine, termed **haustrae**.

5. Either an adventitia or a serosa is present, depending on the particular portion of the large intestine.

B. The **appendix** resembles the large intestine except that the outer longitudinal smooth muscle layer is complete. Additionally, abundant lymphoid tissue is present in the lamina propria to protect against invading microorganisms.

C. Regions

1. **Ascending colon**. Rises on the right side of the abdominal cavity.

2. **Transverse colon**. Horizontal region that passes across the abdomen from right to left below the stomach.

3. **Descending colon**. Descends on the left side of the abdominal cavity.

4. **Sigmoid colon**. "S"-shaped

5. **Rectum** is a 12-cm-long tube continuing from the sigmoid colon. The mucosa of the rectum is similar to that of the majority of the large intestine. The rectum narrows abruptly to become the anal canal.

D. **Anal canal**. The terminal portion of the intestinal tract is about 4 cm long.

1. The intestinal glands disappear and the epithelium undergoes an abrupt transition from simple columnar to stratified squamous with sebaceous and apocrine sweat glands.

2. The inner circular portion of the muscularis externa expands to form the internal anal sphincter. The external anal sphincter is composed of skeletal muscle.

V. The **anus** is located at the level of the external anal sphincter and is covered by stratified squamous keratinized epithelium (skin).

MAJOR DIGESTIVE GLANDS

PANCREAS *(images)*

OVERVIEW

I. Located in the abdomen in the curve of the duodenum and divided into a **head**, **body**, and **tail**

II. Is both an exocrine and an endocrine gland

A. The exocrine portion produces an alkaline secretion containing digestive enzymes that empties into the duodenum.

B. The endocrine portion secretes insulin, glucagon, and somatostatin that regulate blood glucose levels.

STRUCTURE

I. **Exocrine pancreas**

A. Compound acinar gland; the acinar cells secrete numerous digestive enzymes that break down proteins, carbohydrates, lipids, and nucleic acids.

B. Cells show polarity with basal rough endoplasmic reticulum and apical secretory granules.

C. Duct system

1. Ducts begin as **centroacinar cells** located within the acini.

2. Intercalated ducts are lined with simple cuboidal epithelium. Centroacinar cells and cells of the intercalated ducts secrete bicarbonates to neutralize the acidity of the stomach contents (chyme) entering the duodenum.

3. Striated ducts are not present.

4. Interlobular ducts lead into one or more excretory ducts that empty into the duodenum.

D. Resembles the parotid gland except the pancreas has centroacinar cells and fewer ducts.

E. Secretion is regulated by cholecystokinin and secretin from enteroendocrine cells in the small intestine

II. **Endocrine pancreas (islets of Langerhans)**

A. Small clusters of cells, richly supplied by fenestrated capillaries, are scattered throughout the exocrine pancreas; these clusters show no orderly arrangement of secretory cells within the cluster.

B. Predominate cell types and secretions

1. **A cell (alpha cell)**. Secretes glucagon, which elevates glucose levels in the blood

2. **B cell (beta cell)**. Secretes insulin, which lowers blood glucose levels; predominant cell type

3. **D cell (delta cell)**. Secretes somatostatin, which modulates release of the other two major hormones

C. Individual cell types cannot be distinguished with routine hematoxylin and eosin staining.

LIVER *(images)*

OVERVIEW

I. Located in right, upper quadrant of abdominal cavity under the diaphragm

II. Both an exocrine and an endocrine gland

A. Exocrine secretion (bile) is stored in the gall bladder and released into the duodenum. This secretory product contains bile acids that aid in the emulsification of lipids, bilirubin (the breakdown product of hemoglobin), phospholipids, and cholesterol.

B. Endocrine function is the synthesis of plasma proteins, including albumin, clotting factors, and lipoproteins that are released into the liver sinusoids.

III. Additional functions include the metabolization of digested food, storage of

glucose as glycogen, and detoxification of hormones and drugs.

CYTOARCHITECTURE OF THE CLASSIC LIVER LOBULE

I. The classic **liver lobule** resembles a column similar to a stack of covered-wagon wheels.

II. Spokes of the wheels are cords or plates of **hepatocytes** radiating out from a central axis.

III. Spaces between the spokes are occupied by **liver sinusoids** (discontinuous sinusoidal capillaries).

IV. Central axis of the lobule is a **central vein** into which sinusoids drain (i.e., blood is flowing from the periphery of the lobule to the center). The central vein runs parallel to the long axis of the lobule.

V. The perimeter of the lobule (the wheel rim) is difficult to distinguish in the human. The perimeter is denoted by the position of three to six **portal canals (hepatic portal triads)** situated at intervals around the lobule.

   A. Portal canals run parallel to the long axis of the lobule.

   B. Portal canals contain branches of the

      1. **Hepatic portal vein**. Lined with simple squamous epithelium; has the largest diameter of the three structures

      2. **Hepatic artery**. Lined with simple squamous epithelium and two-three layers of smooth muscle

      3. **Bile duct**. Lined with simple cuboidal epithelium; multiple branches may be present

BLOOD SUPPLY AND DRAINAGE OF THE LIVER

I. Blood supply is from two sources

   A. **Hepatic portal vein**

      1. Supplies about 75% of the blood

      2. Carries blood drained directly from the gastrointestinal tract, which, therefore, is deoxygenated and high in absorbed nutrients.

   B. **Hepatic artery**. Supplies oxygenated blood

II. Branches from both vascular sources continue into smaller branches located in the portal canals. Portal canal branches supply the hepatic sinusoids that drain into a central vein. Multiple central veins anastomose to eventually form the three hepatic veins that empty into the inferior vena cava.

FUNCTIONAL MICROANATOMY

I. Sinusoids

A. A variation of discontinuous capillaries, in that gaps exist between endothelial cells and the fenestrations lack diaphragms

B. The basal lamina is lacking beneath the fenestrations.

C. Fenestrations open into a subsinusoidal space, the **space of Disse**, separating the sinusoids from the hepatocytes beneath the space.

D. **Kupffer cells**, liver macrophages, span the sinusoids, filtering debris from the blood.

II. Hepatocytes (liver cells)

A. Arranged as walls one to two cells thick that radiate out from the central vein like the spokes of a wheel

B. Histology

1. Cells are polyhedral in shape.

2. Cells possess one or two nuclei.

3. Cells contain abundant smooth and rough endoplasmic reticulum, Golgi apparatus, mitochondria, and lysosomes. They also contain large accumulations of electron-dense glycogen granules that stain strongly with PAS. Numerous peroxisomes, along with smooth endoplasmic reticulum, carry out detoxification.

4. At intervals between adjacent cells, the plasma membranes bulge inward to form a bile canaliculus, the beginning of the bile transport system.

5. Microvilli project into the space of Disse, increasing surface area of the cells.

FLOW OF BILE FROM LIVER

I. Bile is produced by hepatocytes in the liver and released into **bile canaliculi** located between two adjacent hepatocytes.

II. Bile canaliculi form a meshwork configuration that continues into bile ducts lying in portal canals. These **bile ducts** anastomose to form the left and right **hepatic duct**.

III. The hepatic ducts exit from the liver and fuse to form the **common bile duct**. The bile it contains can either:

   A. Travel directly to the duodenum

   B. Be transported via the **cystic duct** to the gall bladder where it is stored until needed

GALL BLADDER *(images)*

OVERVIEW

I. Stores and concentrates bile produced in the liver

II. Connects, via the **cystic duct**, with the hepatic duct from the liver to form the common bile duct that empties into the duodenum

MICROANATOMY

I. Mucosa

   A. Composed of:

      1. Simple columnar epithelium with short microvilli. Accumulations of mitochondria and glycoprotein-filled secretory vesicles, particularly in the apices of the cells, are prominent.

      2. Lamina propria

      3. Muscularis mucosae is not present.

   B. Is thrown into complex, irregular folds that are particularly evident when the gall bladder is empty.

II. Submucosa

III. Smooth muscle is arranged in an irregular network surrounding the gall bladder.

IV. A serosa covers most of the gall bladder; an adventitia surrounds the portion that is attached to the liver.

CHAPTER 13

RESPIRATORY SYSTEM

OVERVIEW

COMPONENTS OF THE RESPIRATORY SYSTEM

I. In relationship to lungs (listed in order from exterior to interior, i.e., the path of inspired air)

   A. Extrapulmonary

      1. Nasal cavity

      2. Pharynx

      3. Larynx

      4. Trachea

      5. Primary bronchi

   B. Intrapulmonary

      1. Secondary bronchi

      2. Bronchioles

      3. Terminal bronchioles

      4. Respiratory bronchioles

      5. Alveolar ducts

      6. Alveoli

II. According to function (listed in order from exterior to interior

   A. Conducting Portion (Transports air from exterior)

      1. Nasal cavity

      2. Pharynx

3. Larynx
4. Trachea
5. Primary bronchi
6. Secondary bronchi
7. Bronchioles
8. Terminal bronchioles

B. Respiratory Portion (Involved with gas exchange)

1. Respiratory bronchioles
2. Alveolar ducts
3. Alveoli

STRUCTURAL ORGANIZATION OF RESPIRATORY PASSAGEWAYS

I. Conducting portion (nasal cavities through secondary bronchi)

A. Mucosa (mucous membrane). Faces the lumen

1. **Respiratory epithelium. Pseudostratified with cilia and goblet cells***.*

2. Lamina propria of loose connective tissue with blood vessels and nerves

3. Deepest layer of mucosa may consist of:

a. An **elastic lamina** or

b. A **muscularis mucosae** or

c. This layer may be absent.

B. **Submucosa***.* Dense irregular connective tissue with mucous and serous (mixed) glands

C. **Cartilage** or **bone**

D. **Adventitia***.* Loose connective tissue forming the outer layer of the passageway

II. Structural transitions in walls and layers of the passageways from extrapulmonary passageways to alveoli

A. Transitions

1. Layers become thinner as passageways decrease in diameter.

2. Epithelium decreases in height from pseudostratified to simple columnar to simple cuboidal to simple squamous.

3. Goblet cells and mixed glands stop relatively abruptly at the junction of a secondary bronchus with a bronchiole.

4. Cartilage decreases in size, breaks up into plates, and stops relatively abruptly at the junction of a secondary bronchus with a bronchiole.

5. Cilia are gradually eliminated.

B. Results in the formation of the wall of an **alveolus**, where gas exchange occurs

1. Epithelium is simple squamous

2. Connective tissue core with numerous capillaries

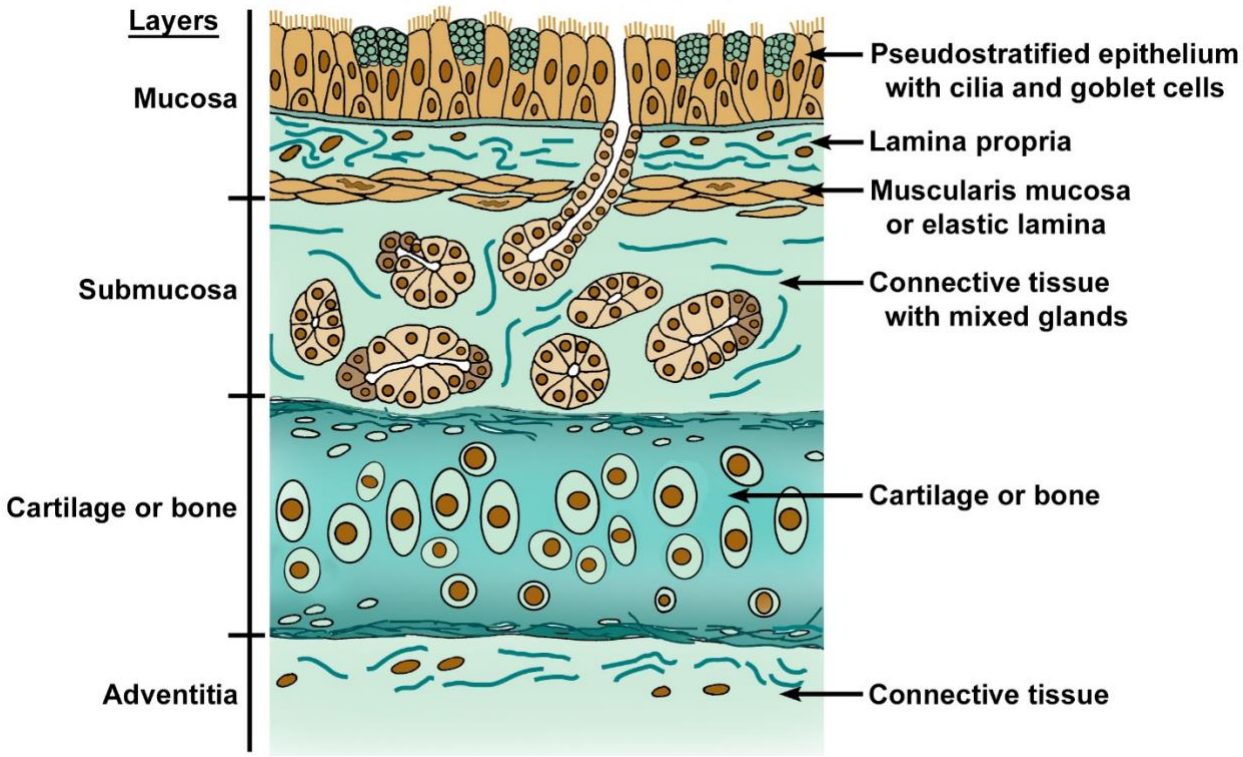


FIGURE 13.1. Layers and components of respiratory passageways.

CONDUCTING PORTION

NASAL CAVITIES (EXTRAPULMONARY) *(images)*

I. The nasal cavities can be subdivided into two regions, the olfactory and the non-olfactory regions.

II. **Non-olfactory region**

A. **Vestibules**. The epithelium undergoes a transition from epidermis of skin with hairs to pseudostratified, respiratory epithelium, with cilia.

B. **Nasal fosse**

1. Typical mucosa but deepest layer is lacking (i.e., neither a muscularis mucosae nor an elastic lamina is present)

2. Patency maintained by bones or cartilage.

C. **Olfactory region**

1. Upside-down, U-shaped area in posterior, superior region of each nasal fossa, extending over a superior concha and about 1 cm down nasal septum

2. Composition of wall

a. Mucosa

i. Epithelium is tall, thick, **pseudostratified columnar** with nonmotile cilia. The epithelium is composed of:

(a). **Olfactory cells** (neurons). Bipolar neurons that respond to odors. A single dendrite extends to the surface to form a swelling, the **olfactory vesicle**, from which nonmotile cilia extend over the surface. These cilia increase surface area and respond to odors.

(b). **Support cells** span the epithelium and support the olfactory cells.

(c). **Basal cells** are located on the basal lamina and serve as reserve cells for the epithelium.

ii. Deepest layer of mucosa is not present, so the lamina propria blends with the submucosa. This connective tissue layer contains

Bowman's glands, serous glands whose watery secretions flush odorants from the epithelial surface.

b. Patency maintained by bone.

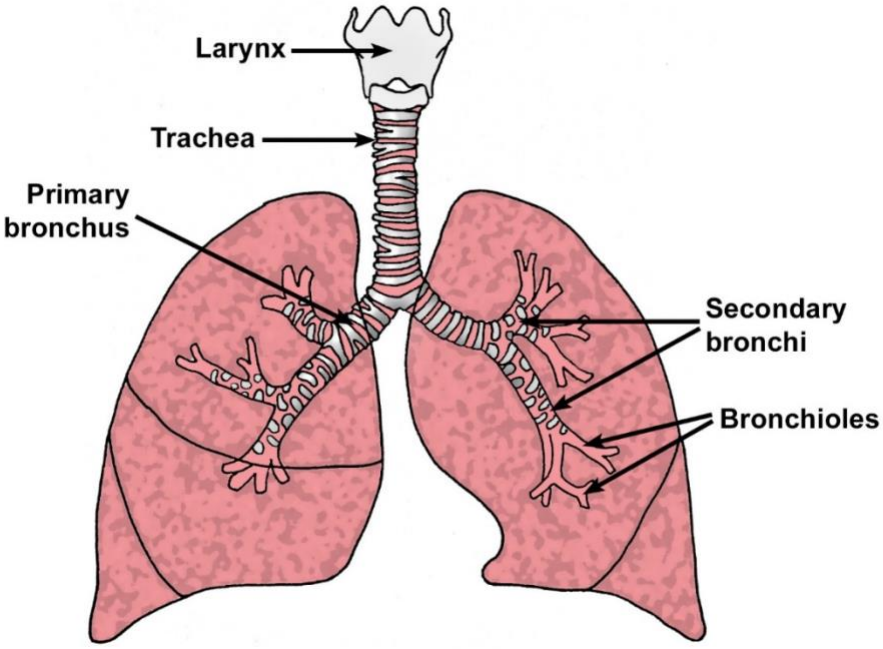


FIGURE 13.2. Conducting portion of the respiratory system.

LARYNX (EXTRAPULMONARY) *(images)*

I. Composition of the wall of the **larynx**

A. Mucosa

1. Epithelium

a. Pseudostratified with cilia and goblet cells in most areas

b. Stratified squamous moist over true vocal folds and much of epiglottis because of friction incurred in these areas

2. No muscularis mucosae or elastic lamina, so lamina propria is continuous with submucosa.

B. Submucosa with mixed glands (except in true vocal fold)

C. Cartilages maintaining patency are numerous, uniquely shaped and are either hyaline or elastic. The larger cartilages are the **epiglottis**, **thyroid**,

and **cricoid**.

D. An adventitia is present.

II. Vocal apparatus. Modification in the larynx composed of two pairs of horizontally positioned mucosal folds located on the lateral walls of the larynx.

A. **False vocal folds**. More superior in location. Resemble the wall of a typical respiratory passageway except the deepest layer of the mucosa is absent (no muscularis mucosae nor elastic lamina).

B. The **ventricle**, a space, separates the false from the true vocal folds.

C. **True vocal folds**

1. Are lined by a stratified squamous moist epithelium and its lamina propria

2. A **vocal ligament** of dense regular elastic connective tissue is located at the edge of the fold, keeping the rim of the fold taut.

3. **Vocalis muscle**, skeletal muscle, lies within each true vocal fold. This muscle alters the shape of the vocal fold and aids in phonation.

TRACHEA AND PRIMARY BRONCHI (EXTRAPULMONARY) ***(images)***

I. The **trachea** and **primary bronchi** are identical in structure and will be considered together.

II. Mucosa

A. Epithelium is pseudostratified with cilia and goblet cells with a very prominent basement membrane

B. Lamina propria of loose connective tissue

C. Elastic lamina of longitudinally arranged elastic fibers

III. Submucosa with mixed glands

IV. **C-shaped cartilage** rings maintain patency; **trachealis muscle** (smooth) interconnects the open ends of the tracheal rings.

V. Adventitia is present.

SECONDARY BRONCHI (INTRAPULMONARY) ***(images)***

I. **Secondary bronchi**

A. The first intrapulmonary structures; a secondary bronchus supplies each of the three lobes of the right lung and the two lobes of the left lung.

B. Similar to, but diminished in size from, the primary bronchi

II. Mucosa

A. Epithelium, pseudostratified with cilia and goblet cells

B. Lamina propria contains numerous, longitudinally arranged elastic fibers.

C. Muscularis mucosae of smooth muscle fibers arranged in crisscrossing bands

III. Submucosa with mixed glands

IV. Patency maintained by **plates of hyaline cartilage***.*

V. Adventitia is present.

BRONCHIOLES (INTRAPULMONARY) ***(images)***

I. Walls of **bronchioles** continue to decrease in size. The greatest changes in histology occur in the walls of the bronchioles as glands and cartilage are eliminated.

II. Mucosa

A. Epithelium

1. Pseudostratified with cilia and goblet cells in largest bronchioles that decreases to:

2. Simple columnar with cilia in smallest bronchioles **(terminal bronchioles)**, but no goblet cells persist.

3. **Clara cells** are present in terminal bronchioles.

a. Tall, dome-shaped, nonciliated cells

b. Possess numerous secretory granules whose contents aid in lowering surface tension of the terminal bronchioles, thus aiding in inspiration

B. Lamina propria contains numerous, longitudinally arranged elastic fibers.

C. Muscularis mucosae. Greatest development of smooth muscle (crisscrossing

bands) in relationship to thickness of wall of all respiratory passageways

III. Submucosa contains no glands.

IV. No cartilages or bones support bronchioles; therefore, submucosa and adventitia form a single connective issue layer.

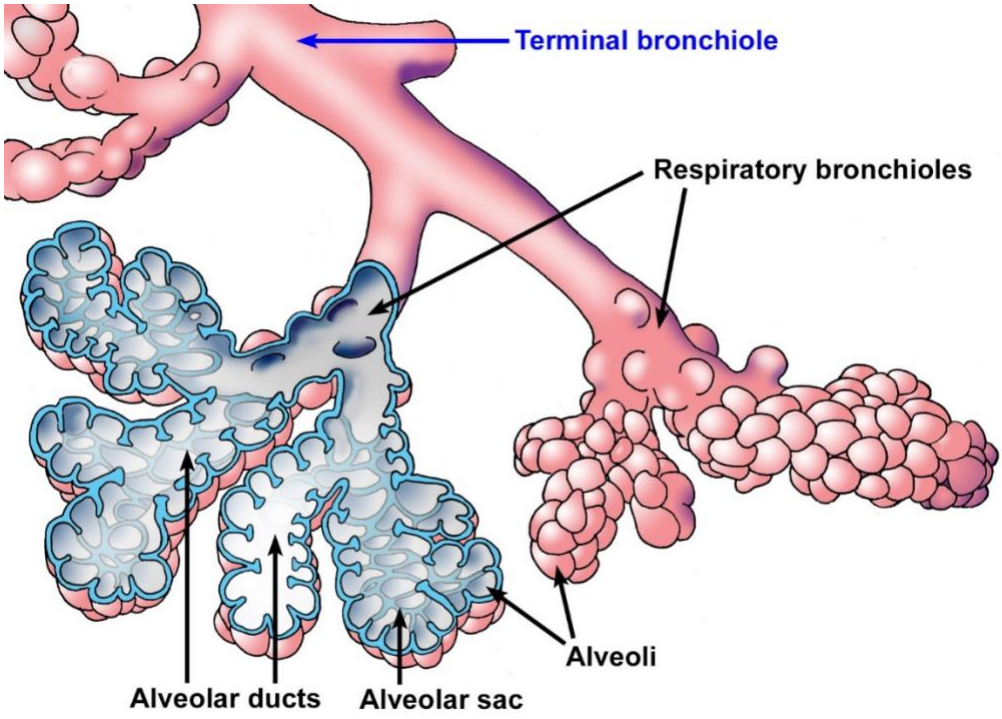


FIGURE 13.3. Components of the respiratory portion of the respiratory system.

RESPIRATORY PORTION

PRIMARY FUNCTION

I. Gas exchange occurs in the alveolus. Therefore, an alveolus must be an integral part of all the passageways of the respiratory part of the respiratory system.

RESPIRATORY BRONCHIOLES *(images)*

I. **Respiratory bronchioles** continue to decrease in diameter and in thickness of their walls.

II. Mucosa.

A. Simple cuboidal epithelium with Clara cells and a few sparsely scattered cilia

B. Longitudinal arranged elastic fibers in lamina propria

C. Muscularis mucosae of smooth muscle

III. Alveoli bulge from wall (i.e., lumen of alveolus is continuous with lumen of respiratory bronchiole).

ALVEOLAR DUCTS *(images)*

I. An **alveolar duct** is formed as the alveoli in a respiratory bronchiole increase in number, thereby decreasing the amount of wall that is present.

A. At the level of the alveolar duct, the "wall" is reduced to a series of rings framing the entrance to an alveolus or a group of alveoli (alveolar sac).

B. When sectioned, these rings resemble knobs to which the alveoli are attached.

II. Wall

A. Simple cuboidal epithelium

B. Elastic fibers and smooth muscle in "knobs"

C. Alveoli bulge from the framework formed by the knobs.

ALVEOLAR SACS

I. **Alveolar sacs** are two or more alveoli arising from a single ring of knobs.

ALVEOLI *(images)*

I. **Alveoli** are thin-walled, hollow polyhedrons forming the bulk of the lungs; where gas exchange occurs.

II. Individual alveoli are components of respiratory bronchioles and alveolar ducts, or multiple alveoli may be grouped together to form alveolar sacs.

III. **Interalveolar septum**. Structure between two adjacent alveoli is composed of:

A. The epithelium lining each alveolus.

1. **Squamous alveolar or type I cells** form a simple squamous epithelium lining 95% of the alveolar surface area and forming a portion of the blood-air barrier.

2. **Septal or type II cells**

    a. Spherical cells with microvilli and abundant, vacuolated cytoplasm; bulge into alveolar space

    b. **Lamellar bodies** in the cytoplasm of septal cells are responsible for the vacuolated appearance of these cells. Lamellar bodies give rise to surfactant, a secretory product consisting of phospholipids, glycosaminoglycans, and proteins.

    c. Serve as progenitors for both type I and type II cells

B. Connective tissue core contains a vast capillary bed that bulges into the alveolar space, elastic fibers, alveolar macrophages, and other connective tissue components.

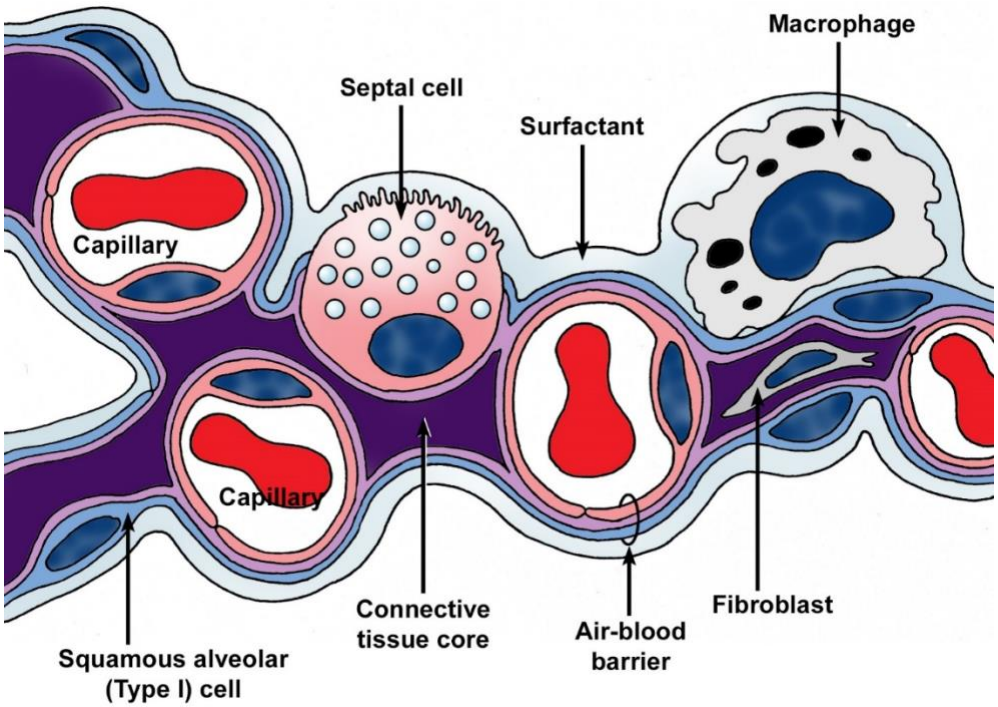


FIGURE 13.4. Components of the interalveolar septum, including the air-blood barrier.

C. Additional components

1. **Pulmonary surfactant**

a. Is an extracellular fluid coating alveolar surfaces

b. Lowers alveolar surface tension, aiding in inflation of alveoli during inspiration, and preventing collapse of alveoli during expiration

c. Is composed of a monomolecular, phospholipid surface film that covers an underlying aqueous hypophase

d. Appears during the last weeks of gestation. Absence or insufficiency of surfactant may result in respiratory distress syndrome or hyaline membrane disease in infants born prematurely.

2. **Alveolar macrophages**

a. Lie free in the alveolar space within the surfactant layer. With congestive heart failure, RBCs pass into alveolar spaces and are phagocytized by these macrophages, which are then called "heart failure" cells.

b. Are located within the connective tissues of all respiratory passageways. Macrophages that engulf dust and carbon particles are called dust cells.

3. **Alveolar or Kohn's pores**. Small openings in the interalveolar septa between neighboring alveoli that aid in equalizing interalveolar pressure. These pores can contribute to the spread of bacteria in the lung.

AIR-BLOOD BARRIER

I. The **air-blood barrier** separates air from blood. Oxygen and carbon dioxide must cross this barrier during gas exchange.

II. Composition

A. Squamous alveolar (type I) cell with its basal lamina

B. Capillary endothelial cell with its basal lamina

C. In most cases the basal laminae are fused.

PLEURA *(images)*

I. The **pleura** is a serous membrane (serosa) that lines each thoracic cavity and is reflected over the exterior surface of each lung.

II. Composition

A. Simple squamous epithelium **(mesothelium)**

B. Underlying connective tissue layer with elastic fibers

III. Produces a fluid film that lubricates the surface of the lungs and provides surface tension for lung expansion

IV. Components

A. **Visceral pleura**. Pleura reflected over the surface of the lung

B. **Parietal pleura**. Pleura reflected onto the inner body wall

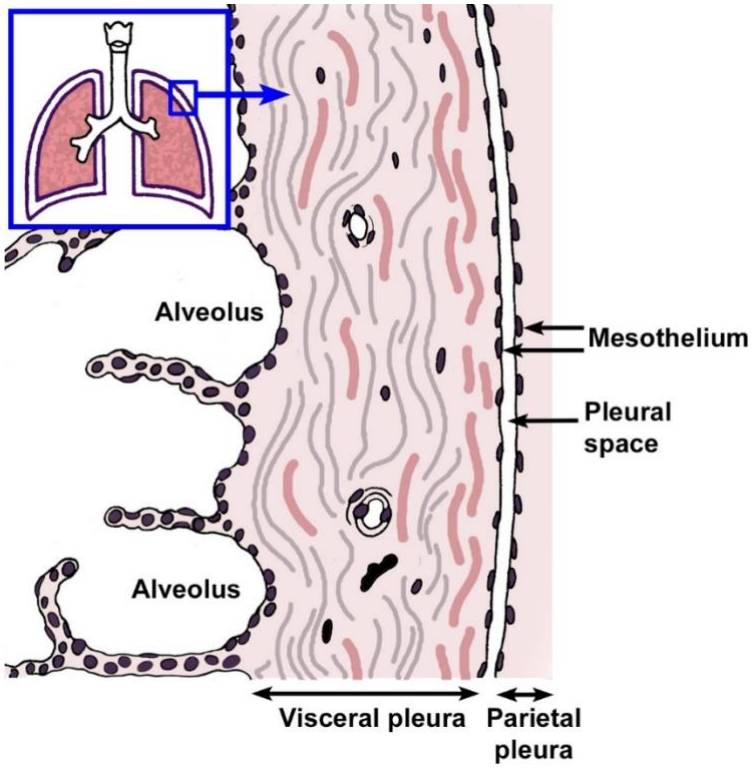


Figure 13.5 Pleura

VASCULAR SUPPLY TO LUNG *(images)*

I. Pulmonary circulation supplies deoxygenated blood for gas exchange

A. The **pulmonary artery** and its branches travel adjacent to the bronchial passageways, supplying deoxygenated blood to the pulmonary capillaries. Pulmonary arteries are comparable in diameter to their neighboring

respiratory passageways.

B. **Alveolar (pulmonary) capillaries** lie in the interalveolar septa, forming part of the air-blood barrier. These abundant capillaries anastomose to form pulmonary veins.

C. **Pulmonary veins** carry oxygenated blood, and travel alone in the parenchyma away from respiratory passageways. After leaving a lung lobule, pulmonary veins, the bronchial passageways, and pulmonary arteries collect near the hilum of the lung.

II. **Bronchial circulation** supplies oxygenated blood and nutrients to the tissue layers forming the walls of the bronchial passageways. These vessels, therefore, lie within and are much smaller than the wall of the passageways they supply.

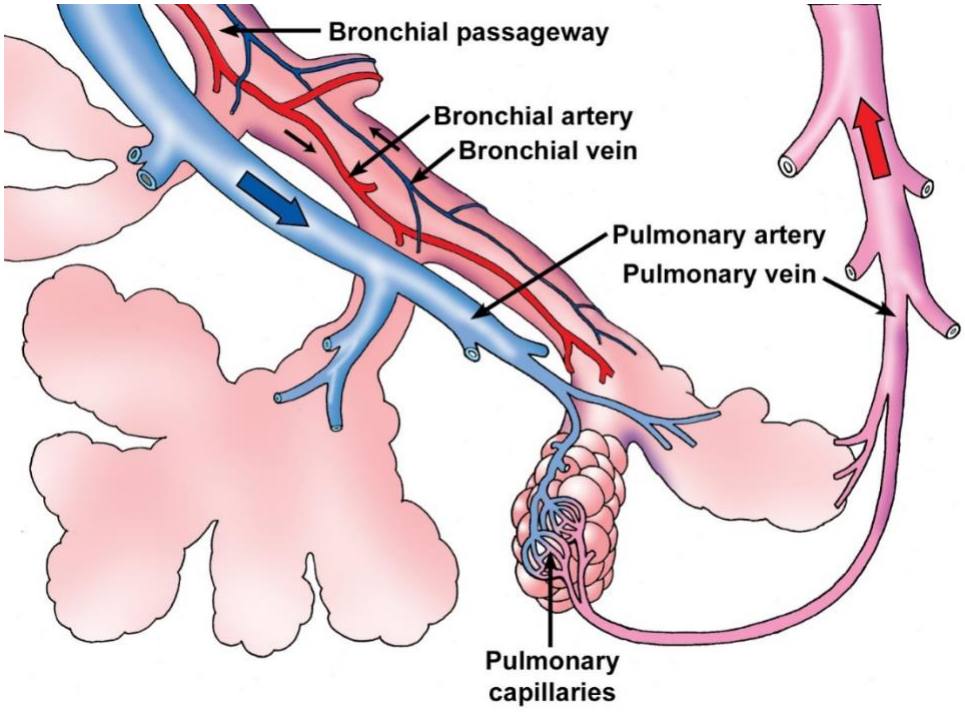


FIGURE 13.6. Vascular supply to the lungs. Arrows indicate direction of blood flow.

CHAPTER 14

LYMPHOID SYSTEM

GENERAL CONCEPTS

I. Functions

A. Provides immune surveillance and defense against foreign substances and microorganisms

B. Provides immune tolerance, distinguishing between "self" and "non-self"

C. Absorbs lipids into small lymphoid vessels (lacteals) in intestinal villi for distribution to the blood stream and liver

D. Helps to maintain fluid balance by accumulating tissue fluid and white blood cells in lymph vessels and returning them to the blood

II. Overview of lymphoid components

A. **Primary lymphoid organs and structures**

1. **Bone marrow**. Site of origin of T and B lymphocytes. B lymphocytes directly seed secondary lymphoid structures and organs.

2. **Thymus**. T lymphocytes from bone marrow undergo further maturation in the thymus before seeding secondary lymphoid structures and organs.

B. **Secondary lymphoid organs and structures** (from least to most complex)

1. **Diffuse lymphoid tissue**

2. **Lymphoid nodules**. Both solitary and in aggregates.

3. **Tonsils**

4. **Lymph nodes**

5. **Spleen**

C. Major lymphoid cell types

1. **B lymphocytes** originate and mature in the bone marrow, then seed secondary lymphoid structures and organs. B cells differentiate into B memory cells and plasma cells, providing humoral immunity.

2. **T lymphocytes** originate in bone marrow, mature in the thymus, and subsequently seed secondary lymphoid tissue. T cells differentiate into helper, memory, and cytotoxic cells. T lymphocytes provide cell-mediated immunity and assist B lymphocytes in their humoral response.

3. **Plasma cells** differentiate from B lymphocytes and produce humoral antibodies.

4. **Macrophages** and **dendritic cells** phagocytose foreign matter, enhance the body's response to antigen by "presenting" antigen to lymphocytes, and secrete immunomodulatory factors.

D. **Lymph vessels *(images)***

1. Are thin-walled vessels lined with endothelium

2. Begin as blind-ended lymphatic capillaries in tissues. These capillaries accumulate tissue fluid, which is called lymph once it is enclosed by the capillary.

3. Gradually increase in diameter and have valves located within their walls. Lymph nodes are positioned along these vessels.

4. Unite to form two **lymph ducts** (thoracic and lymphatic ducts) that return lymph to the venous side of the blood vasculature system

E. **High endothelial venules (HEVs) *(images)***

1. Located in appendix, tonsils, Peyer's patches, and especially in lymph nodes, but not in spleen

2. Endothelium lining these venules is simple cuboidal rather than simple squamous epithelium

3. Allow transport of lymphocytes through the endothelium, thus permitting diapedesis of these cells and the dissemination of immunological information between different regions of the body

F. Stroma of lymphoid structures and organs

1. **Reticular cells** produce reticular fibers and act as fixed macrophages as they ensheathe these fibers. Reticular cells and reticular fibers together constitutes reticular connective tissue.

2. **Reticular fibers** are composed of collagen type III and form a meshwork that allows fluid to percolate through it while providing delicate, nondistensible support for cells suspended within it.

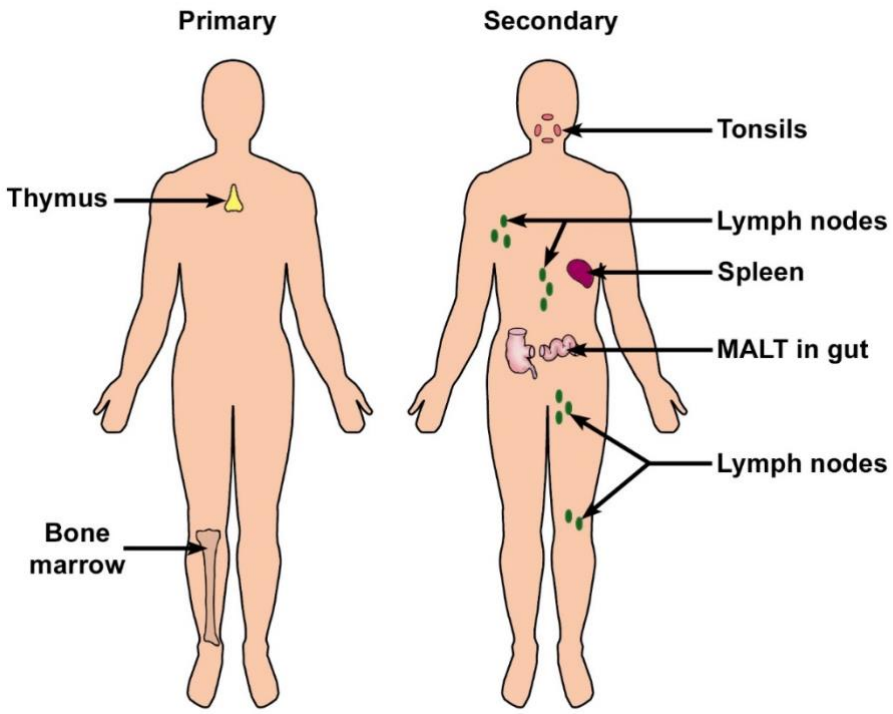


FIGURE 14.1. The primary and secondary lymphoid structures and organs. MALT, mucosal-associated lymphoid tissue.

COMPONENTS OF THE LYMPHOID SYSTEM

I. **Diffuse lymphatic tissue *(images)***

A. Located in lamina propria of any organ system opening to the exterior of the body, such as respiratory and digestive systems, where an antigen could penetrate the epithelium and enter the lamina propria. Diffuse lymphoid tissue in the lamina propria is part of the **mucosal-associated lymphoid tissue (MALT)**. Diffuse lymphatic tissue is also located in tonsils, lymph nodes, and spleen.

B. Composed of an unorganized cluster of lymphocytes and other cells capable of responding to an antigen that reaches it.

C. Filters and provides immune surveillance for tissue fluid of the lamina propria in which it is located

II. **Lymphoid nodules *(images)***

A. Distribution

1. Lamina propria of any organ opening to the exterior of the body. May occur singly (solitary) or in clusters (aggregates) such as in tonsils and

Peyer's patches in the small intestine. Lymphoid nodules in the lamina propria are part of MALT.

2. Lymph node and spleen

B. Structure

1. **Primary nodule**. The nodule present before antigen stimulation. The spherical nodule consists primarily of densely packed B lymphocytes.

2. **Secondary nodule**. After antigen stimulation, a central pale core, the **germinal center**, appears. This center is composed of immunoblasts that divide to form lymphocytes that accumulate in the densely packed, peripheral zone of the nodule.

C. Function

1. Filter and provide immune surveillance for the fluid of the layer/organ in which it is located: tissue fluid in the lamina propria, lymph in lymph nodes, and blood in the spleen.

2. Detect specific antigens and causes proliferation of antigen-specific B lymphocytes

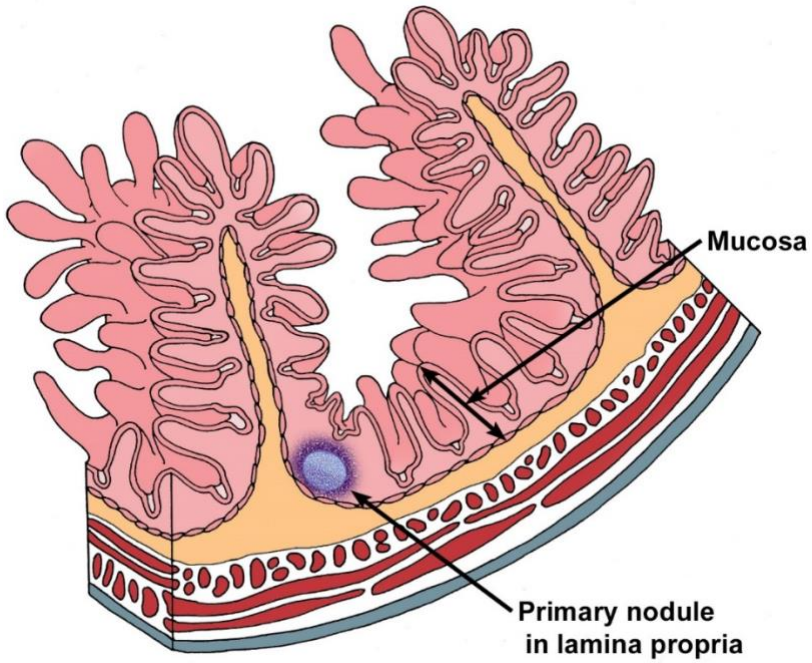


FIGURE 14.2. Nodular lymphoid tissue in the mucosa is part of MALT, mucosal associated lymphoid tissue. Longitudinal section of the small intestine.

III. **Tonsils *(images)***

A. **Pharyngeal**, **lingual**, and **palatine tonsils** are located at the junction of the oral cavity with the oral pharynx and in the nasopharynx.

B. Located in the lamina propria of the mucosa

C. Structure

1. Aggregations of lymphoid nodules and diffuse lymphoid tissue

2. **Crypts** or folds of surface epithelium invade the tonsils.

3. Partially encapsulated by connective tissue separating it from underlying tissues

D. Filter and provide immune surveillance for the tissue fluid of the lamina propria in which they are locate

IV. **Lymph nodes *(images)***

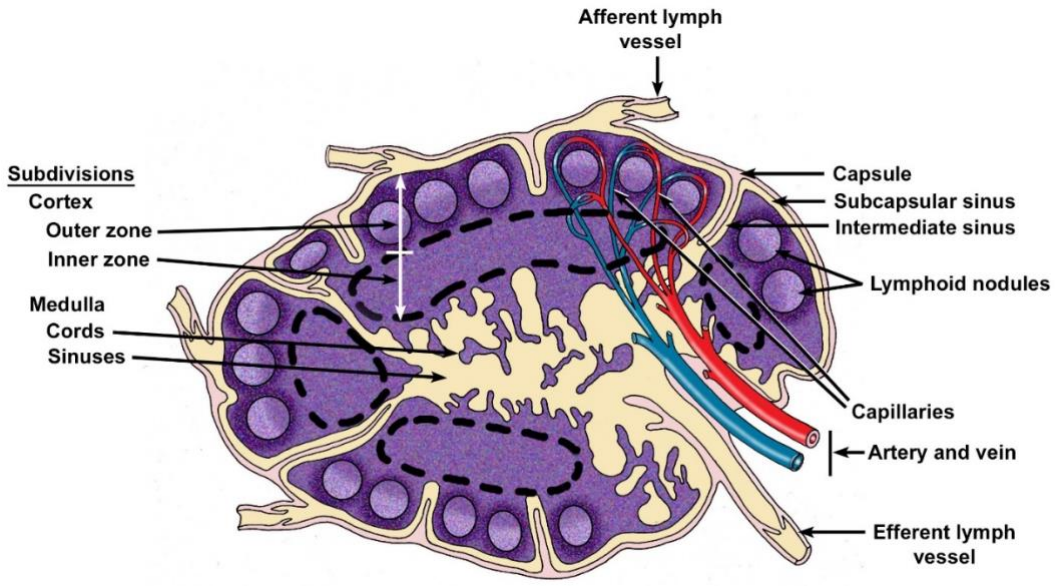


FIGURE 14.3. Lymph node.

A. Small, encapsulated, kidney-shaped organs occurring in chains or groups along lymph vessels

B. Structure

1. **Cortex**

a. **Capsule** of dense connective tissue surrounds the node and sends short trabeculae into the node. Reticular connective tissue forms the stroma for the remainder (interior) of the node.

b. **Outer zone**. Filled primarily with lymphoid nodules composed of B lymphocytes

c. **Inner zone (paracortex or deep cortex)**. Filled with diffuse lymphoid tissue composed of T lymphocytes

d. **Sinuses** in cortex. Loose network of macrophages and reticular fibers through which lymph percolates

i. **Subcapsular sinus** lies immediately beneath the capsule and receives incoming lymph fluid from afferent lymphatic vessels that enter through the capsule.

ii. **Intermediate sinuses**. Lie adjacent to the trabeculae. Receive lymph from the subcapsular sinus and continue as medullary sinuses

2. **Medulla**. Composed of:

a. **Medullary cords** of B lymphocytes that extend from the inner cortex into the medulla

b. **Medullary sinuses**. Continuations of the intermediate sinuses in the cortex. Lymph flows from medullary sinuses into the efferent lymph vessels that exit at the hilum of the node.

C. Blood supply. Small arteries enter at the hilum to supply a capillary plexus in the outer cortex. The capillaries anastomose to form HEVs in the paracortex and small veins that exit at the hilum.

D. Filter and provide immune surveillance for lymph

V. **Spleen *(images)***

A. Encapsulated, intraperitoneal organ located in upper left quadrant of the abdominal cavity

B. Structure

1. **Capsule** surrounds organ, sending trabeculae into the spleen. Larger blood vessels traverse the trabeculae.

2. Subdivisions

a. **White pulp** appears white in fresh specimens and is composed of:

i. **Periarterial lymphoid sheath (PALS)**. A sleeve of T lymphocytes that surrounds a central arteriole as soon as it exits from a trabecula

ii. **Lymphoid nodules**, composed of B lymphocytes, are randomly located along and embedded in the PALS.

b. **Red pulp** appears red in fresh specimens because of the abundant venous sinuses it possesses.

i. **Splenic cords (of Billroth)**. Cords of lymphocytes (T and B), macrophages, plasma cells, and other lymphoid cells suspended in a reticular connective tissue stroma. Surrounded by:

ii. **Splenic sinuses**. Venous sinuses separating splenic cords. These sinuses are lined by endothelial cells and surrounded by reticular fibers.

3. The spleen filters and provides immune surveillance for the blood percolating through it. The spleen also phagocytoses aged and abnormal erythrocytes and stores blood.

C. Blood flow through the spleen

1. **Splenic artery** enters at the hilum of the spleen and branches into arteries that lie in the trabeculae.

2. Arteries exit from the trabeculae as **central arterioles** and are immediately surrounded by the PALS. The central arteriole becomes eccentrically located when it is displaced by a lymphoid nodule. Branches from the central arterioles supply the PALS, including forming marginal sinuses at the perimeter of the white pulp.

3. Central arterioles lose their PALS ensheathment and form a series of smaller arterioles in the red pulp. These arterioles either:

a. Open directly into a splenic sinus **(closed circulation)**

b. Open into a splenic cord where the blood percolates through the cells of the cord before entering a splenic sinus **(open circulation)**

4. **Trabecular veins** are formed by splenic sinuses anastomosing and then entering a trabecula. Trabecular veins anastomose to form the splenic vein.

5. The **splenic vein** exits at the hilum of the spleen.

VI. **Thymus** ***(images)***

A. The thymus is a primary lymphoid organ that receives immature lymphocytes (thymocytes) from the bone marrow. These cells mature in the thymus and are carried to secondary lymphoid structures/organs via the blood vascular system.

B. The thymus is located in the superior mediastinum under the sternum. The thymus involutes with age.

C. Structure

1. A connective tissue **capsule** surrounds the thymus and extends into the thymus, dividing it into lobules.

2. The **stroma** is formed by a network of reticular cells of endodermal, rather than the usual mesodermal, origin and are called, therefore, **epithelial reticular cells**. These cells do not form fibers.

3. Each lobule contains an:

   a. Outer **cortex** that is densely packed with thymocytes, the developing T lymphocytes. These cells mature in the cortex, then migrate into the medulla where they enter the blood stream for transport to secondary lymphoid structures and organs.

   b. Inner **medulla** has fewer thymocytes and, therefore, stains more palely than does the cortex. **Hassall's corpuscles** are the degenerating remains of the epithelial reticular cells with their keratin granules and are diagnostic for the thymus.

D. A blood-thymic barrier is formed around capillaries in the cortex, so that the developing lymphocytes are not exposed to circulating antigens.

Chapter 15

URINARY SYSTEM

COMPONENTS

I. **Kidneys**. Contain the **uriniferous tubules**, which consist of nephrons and a system of collecting ducts; filter blood and produce urine

II. **Ureters**. Muscular tubes that collect urine output from the kidney and carry it to the urinary bladder

III. **Urinary bladder**. Hollow muscular organ that stores urine

IV. **Urethra**. Tube that drains urine from urinary bladder to the exterior

FUNCTIONS OF THE URINARY SYSTEM

I. Excretion of waste products of metabolism

II. Regulation and maintenance of the fluid volume of the body Regulation of acid-base balance

III. Regulation of salt concentrations and other compounds in body fluid

IV. Production of renin, an enzyme that influences blood pressure

MACROSCOPIC ORGANIZATION OF THE KIDNEY

I. **Cortex**. Broad outer zone of kidney

   A. Subdivisions

      1. **Cortical labyrinth**. "True" cortical tissue

      2. **Medullary rays**. Medullary tissue located in the cortex

   B. Contains renal corpuscles, portions of renal tubules, and collecting ducts

II. **Medulla**. Deep to cortex

   A. Subdivisions

      1. **Renal pyramids**. Inverted cones whose bases are adjacent to the cortex;

send "stripes" of medullary tissue into the cortex forming the medullary rays

2. **Renal columns**. Extensions of cortical tissue between renal pyramids

B. Consists of portions of renal tubules and collecting ducts

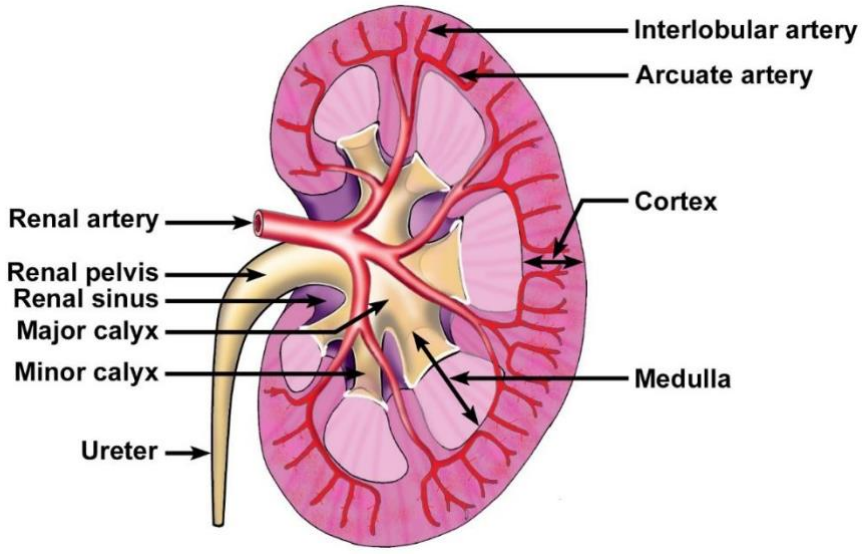


FIGURE 15.1. Extrarenal passageways and vascular supply of the kidney.

III. Renal lobulations

A. **Renal lobe**. A medullary pyramid, the surrounding renal column extending to the interlobar vessels, and the overlying cortical tissue

B. **Renal lobule**. A central medullary ray and the adjacent cortical labyrinth extending to the interlobular vessels

IV. Extrarenal passageways

A. **Minor calyx**. Funnel-shaped structure (one for each pyramid) into which the point (apex) of a pyramid projects; urine flows from the pyramid into a minor calyx and several minor calyces unite to form a major calyx.

B. **Major calyx**. Four or five per kidney; formed by the confluence of minor calyces

C. **Renal pelvis**. Structure formed by the uniting of the major calyces; forms the expanded upper portion of the ureter

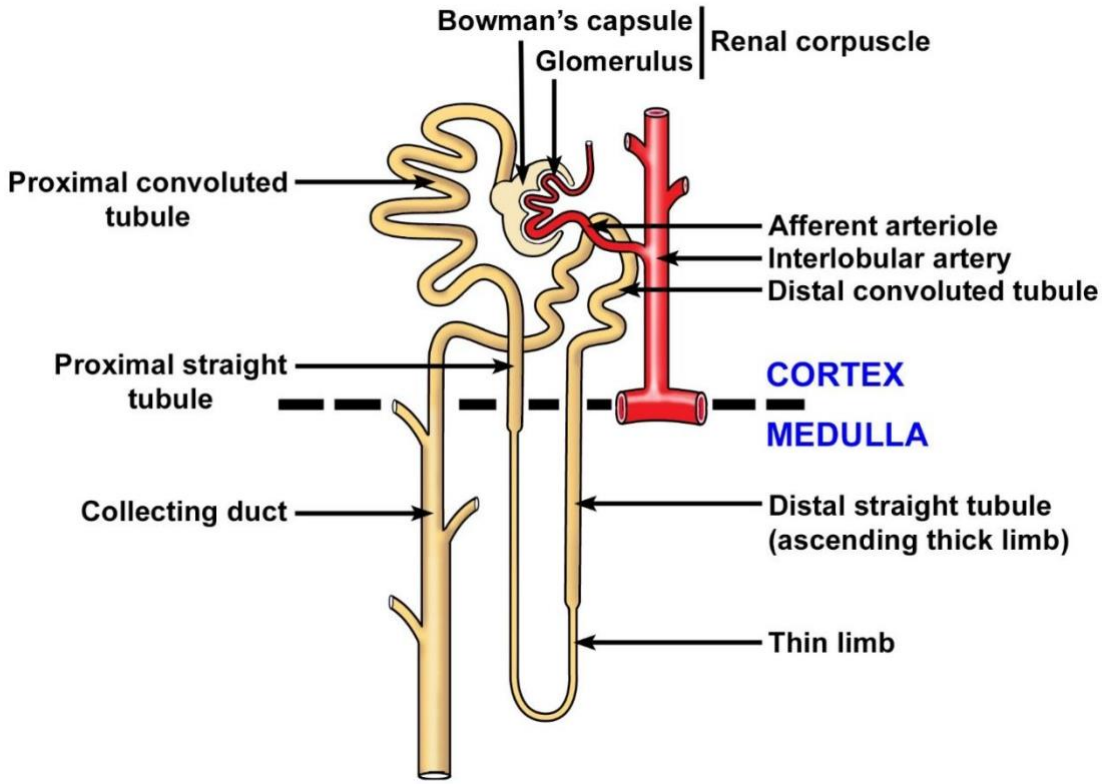


FIGURE 15.2. The nephron, collecting tubule, and associated blood supply.

THE NEPHRON

I. 1.5-2 million per kidney

II. **Renal corpuscle *(images)***

A. Located in the cortical labyrinth

B. Components

1. **Glomerulus**. A tuft of fenestrated capillaries, whose pores lack diaphragms; filter blood. Formed by an afferent arteriole, the glomerulus indents into Bowman's capsule like a baseball fits into a baseball glove. Blood leaves the glomerulus via the efferent arteriole.

2. **Bowman's capsule**. Double-walled, epithelial capsule with central space called **Bowman's space**; surrounds the glomerulus and receives the fluid filtered from the blood

a. **Parietal layer**. Outer layer, simple squamous epithelium which is reflected at the vascular pole of the renal corpuscle to become the visceral layer; continuous with the proximal tubule at the urinary pole

b. **Visceral layer**. Inner layer surrounding the glomerulus. Consists of a single layer of modified epithelial cells called **podocytes**. The radiating foot processes of these cells give rise to many secondary processes called **pedicels**. Pedicels of adjacent podocytes interdigitate and surround the glomerular capillaries. The slits *(***filtration slits***)* between the pedicels are bridged by **slit diaphragms**.

3. **Filtration barrier**. Barrier between blood in glomerular capillary and space of Bowman's capsule

   a. Fenestrated endothelium of glomerular capillary

   b. Thick, fused basal laminae of the podocytes and the glomerular endothelial cells

   c. Slit diaphragms between pedicels of visceral layer of epithelium

4. Poles of the glomerulus

   a. **Vascular pole**. Where afferent and efferent arterioles enter and leave the renal corpuscle, respectively

   b. **Urinary pole**. Where the parietal layer of Bowman's capsule is continuous with the proximal convoluted tubule

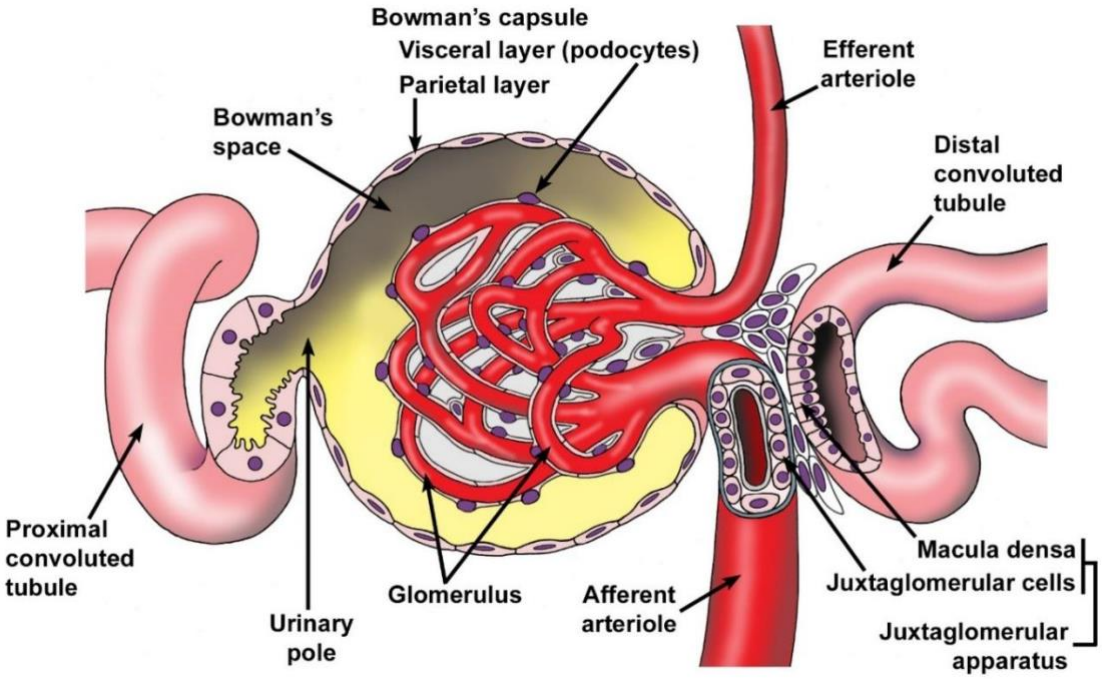


FIGURE 15.3. The renal corpuscle and associated structures.

III. Renal tubule ***(images)***

A. The glomerular filtrate of the blood continues from Bowman's space into the renal tubule, which meanders first through the cortex, then the medulla, then back to the cortex, and finally enters the collecting duct.

B. Regions of the renal tubule

1. Listed in order are regions of the renal tubule through which urine passes

    a. **Proximal convoluted tubule**

    b. **Proximal straight tubule**

    c. **Thin limbs**

    d. **Ascending thick tubule (distal straight tubule)**

    e. **Distal convoluted tubule**

2. **Proximal tubule, convoluted portion**

    a. Located in labyrinth of cortex; highly convoluted

    b. Interconnects parietal epithelium of Bowman's capsule with straight portion of proximal tubule

    c. Composed of a simple cuboidal epithelium with microvilli; cells possess numerous infoldings of the basal plasma membrane and many mitochondria

    d. Absorption of glucose, amino acids, and the majority of salt and water occur here.

3. **Loop of Henle**. Located in medullary tissue (i.e., medullary ray and medulla)

    a. **Proximal tubule, straight portion (thick descending limb of the loop of Henle)**

        i. Located in the medullary ray (in cortex) and continues into the medulla

        ii. Interconnects proximal convoluted tubule with thin limb of Henle's loop

        iii. Histology is identical to that of the proximal convoluted tubule

iv. Absorption of same substances as in proximal convoluted tubule

b. **Thin segment**

i. Found in medulla

ii. Interconnects proximal straight tubule with distal straight tubule

iii. Frequently makes the "loop" in the loop of Henle

iv. Composed of a simple squamous epithelium

v. Actively pumps out chloride, with sodium following passively, to produce a hypertonic urine

c. **Distal tubule, thick ascending limb of the loop of Henle.**

i. Begins in the medulla and continues into the medullary ray (in cortex)

ii. Interconnects thin segment with distal convoluted tubule

iii. Composed of a simple cuboidal epithelium with inconsistent microvilli. The cytoplasm is less acidophilic and the lumen is wider than in the proximal tubule. The basal plasma membrane is extensively infolded with numerous mitochondria between the folds.

iv. Returns to a glomerulus to form part of the juxtaglomerular apparatus.

v. Major site of salt and water control in the body

4. **Distal tubule, convoluted portion**

a. Located in the labyrinth portion of cortex; highly convoluted

b. Interconnects the ascending thick limb with collecting tubule

c. Histology is identical with the distal straight tubule

d. Major site of salt and water control in the body

C. **Juxtaglomerular (JG) apparatus**

1. Located at the vascular pole of a nephron; helps regulate blood pressure

2. Composition

    a. **Juxtaglomerular cells**. Modified smooth muscle cells in wall of an afferent arteriole

    b. **Macula densa**. Cluster of modified cells in the wall of a the ascending thick limb adjacent to the juxtaglomerular cells. The clustering of cells, and therefore of their nuclei, gives the appearance of a "dense spot" in the wall of the distal convoluted tubule.

3. Monitors the tonicity of the urine in the tubule. The macula densa affects the adjacent JG cells to adjust their production of renin, an enzyme that aids in regulating blood pressure.

EXCRETORY TUBULES AND DUCTS AND EXTRARENAL PASSAGES *(images)*

I. Separate embryological origin from the nephron

II. Components

A. **Collecting tubule**

1. Composed of simple cuboidal to simple columnar cells; usually displays distinct lateral boundaries between cells

2. Drains urine from the distal convoluted tubule of many nephrons in the cortical labyrinth, enters the medullary ray in the cortex and descends into the medulla

3. Joins with other collecting tubules to form the papillary ducts (of Bellini)

4. Aids in concentrating the urine

B. **Papillary ducts (of Bellini)**. Located deep in the medullary pyramid near the minor calyces; composed of a tall, pale, simple columnar epithelium. Empty into the minor calyx at the area cribosa at the apex of each pyramid

C. **Minor** and **major calyces**. Transport urine to the renal pelvis and into the ureter; lined by **transitional epithelium**

D. **Renal pelvis**. Expanded origin of the ureter, lined by transitional epithelium; formed by the union of major calyces

E. **Ureter**. Muscular tube connecting the renal pelvis and the urinary bladder, lined by transitional epithelium; two layers of smooth muscle in the upper two-thirds, inner longitudinal and outer circular, with the addition of a third outer longitudinal layer in the lower one-third

F. **Urinary bladder**. Lined by a transitional epithelium, a stratified cuboidal epithelium specialized to provide for distension of the organ; a thick muscular wall contains three interlacing layers of smooth muscle.

BLOOD SUPPLY OF THE KIDNEY

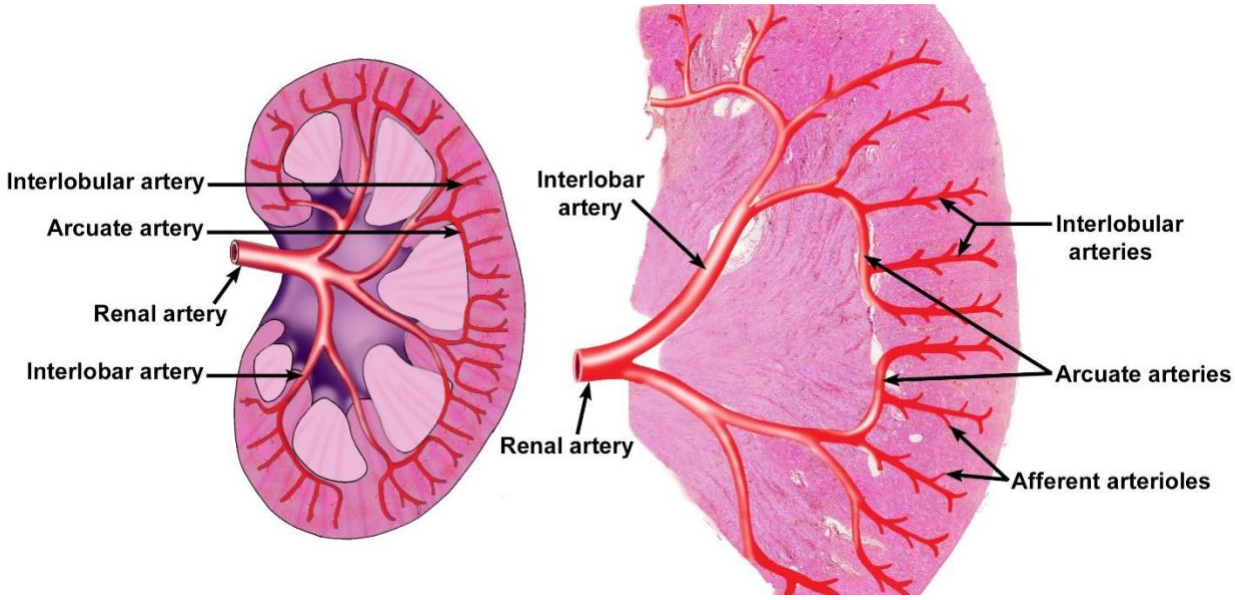


FIGURE 15.4. Blood supply of the kidney

I. **Renal artery**. A branch of the aorta, enters the kidney at the *hilus;* branches to form the interlobular arteries

II. **Interlobar arteries**. Lie between adjacent pyramids in renal columns and branch into arcuate arteries

III. **Arcuate arteries**. Arch between medulla and cortex; give rise to interlobular arteries

IV. **Interlobular arteries**. Branch perpendicular to the arcuate artery in the cortex and lie between adjacent lobules; supply a number of afferent arterioles

V. **Afferent arterioles** supply the glomerulus, entering at the vascular pole of the renal corpuscle

VI. **Glomerulus**. A tuft of capillaries protruding into Bowman's capsule where blood is filtered.

VII. **Efferent arteriole** exits from the glomerulus and forms either **peritubular capillaries**, which nourish the convoluted tubules, or the **vasa recta**. The vasa

recta parallel the straight portions of the renal tubule into the medulla and play an important role is concentrating the urine.