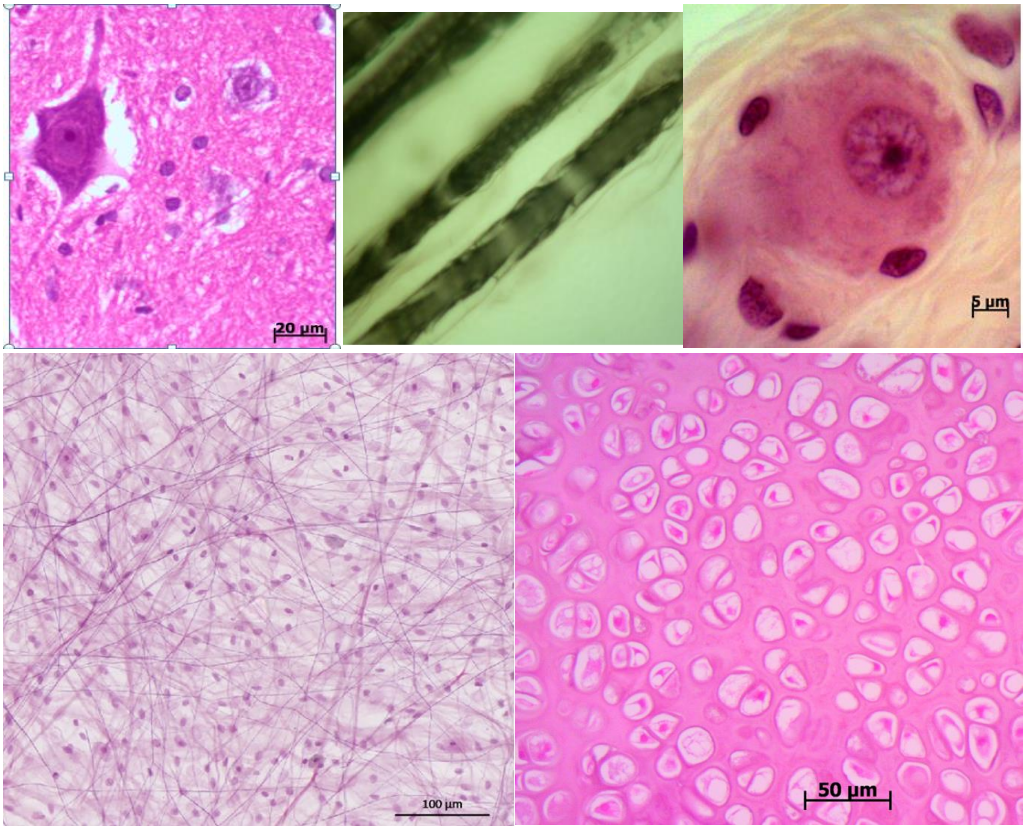
Color Atlas of Basic Tissues



Full-colored photomicrographs for use in the histology laboratory, Brief text and Self-assessment section provided test photomicrographs for identification of basic histological tissues.

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Preface

I hope that the Color Atlas of Basic Tissues will help the preclinic medical students in Chulalongkorn University in taking the course Fundamentals of Tissue Biology and Human function (3000111). It contains full-color photomicrographs in LM for use in histological laboratory of Faculty of medicine, Chulalongkorn University. There is the self-assessment section which provides 43 test photomicrographs for identification of structures and basic tissues including their functions.

Thanks to the Department of Anatomy, Faculty of medicine, Chulalongkorn University for extending my retirement, it has given me the chance to create this book for my first-year medical students.

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Epithelial Tissue

Introduction

Tissues are aggregations or groups of cells organized to perform one or more specific functions.

The tissue concept provides a basis for understanding and recognizing the many cell types within the body and how they interrelate.

There are four basic types of tissues.

1. **Epithelium (epithelial tissue)** covers body surfaces (except the articular cartilage), lines body cavities, and forms glands
2. **Connective tissue** underlies or supports the other three basic tissues, both structurally and functionally.
3. **Muscle tissue** is made up of contractile cells and is responsible for movement.
4. **Nerve tissue** receives, transmits, and integrates information from outside the body to control the activities of the body.

In classifying the basic tissues, two different definitional parameters are used. The basic for definition of epithelium and connective tissue is primarily morphologic; for muscle and nerve tissue, it is primarily function.

Recognition of tissues is based on the presence of specific components within cells and on specific cellular relationships.

Epithelial Tissue (Epithelium)

Categorized to two types (1) covering and (2) glandular epithelium.

Main features of epithelia (covering and glandular epithelium)

- They derive from the ectoderm, mesoderm, and endoderm.
- They cover body surfaces except the articular cartilage, the enamel of the tooth, and the anterior surface of the iris.
- They line body cavities, internal closed cavities (including the vascular organs), and body tubes that communicate with the exterior (the alimentary, respiratory, and genitourinary tracts). They constitute glands that form the secretory portion (parenchyma of glands) and their ducts.

- In addition, specialized epithelial cells constitute neuroepithelia (Fig.1-14) of the special senses (smell, taste, hearing, and vision).
- Their basic functions are protection (skin), absorption (small and large intestine), transport of material at the surface (mediated by cilia), secretion (glands), excretion (tubules of kidneys), gas exchange (lung alveolus), and gliding between surfaces (mesothelium).
- Most epithelial cells renew continuously by mitosis.
- They lack a direct blood and lymphatic supply. Nutrients are delivered by diffusion through the basal lamina.
- The epithelial cells have almost no free intercellular substance.
- The cohesive nature of an epithelium is maintained by cell adhesion molecules and junctional complexes.
- They are anchored to a basal lamina. The basal lamina and connective tissue components cooperate to form the basement membrane.
- They have structural and functional polarity.
- Special epithelial cells function as receptors for the special senses (smell, taste, hearing, and vision).

1. Covering Epithelium

1 **Classification of the covering epithelia**. It bases on three parameters:

1.1 The *shape of individual cells.* Individual cells can be flattened (squamous cells), have equal dimensions (cuboidal cells) and be taller than wider (columnar cells).

1.2 The *number of cell layers.* The epithelium consisting of a single cell layer and of more than one cell layer is classified as simple epithelium and stratified epithelium, respectively. There are 2 special categories are the pseudostratified epithelium and the urothelium. The pseudostratified epithelium consists of basal and columnar cells resting on the basal lamina. Only the columnar cells reach the luminal surface. Because the nuclei of the basal and columnar cells are seen at different levels' one has impression of a stratified epithelial organization.

1.3 The *shape of cells at the outermost layer* into stratified squamous epithelium, stratified cuboidal epithelium, and stratified columnar epithelium.

2 **Epithelial cell polarity**: It is essential to carry out specific functions of the various organ systems. Polarity is determined by the distribution of proteins and lipids and the arrangement of the cytoskeleton. Most epithelial cells lining surfaces and cavities and have three geometric domains.

2.1 **The apical domain** is exposed to lumen or external environment and displays three apical differentiations, (1) ***Cilia*** (two types, (i) multiple motile cilia, and (ii) a single or a primary non-motile cilium), (2) ***Microvilli*****,** and (3**)** ***Stereocilia*****.**

2.2 **The lateral domain** faces neighboring epithelial cells linked to each other by cell adhesion molecules and junctional complexes.

2.3 **The basal domain** is associated with a basal laminin that separates the epithelium from underlying connective tissue. The basal lamina - connective tissue complex is designated the *basement membrane.*

Note: From the functional perspective, sealing junctions segregate the plasma membrane of an epithelial cell into an apical domain and a basolateral domain.

3 **Cell adhesion molecules** can be classified as:

3.1 **Ca^{2+}-dependent molecules (CAMs),** i.e., Cadherins and selectin.

a) *Cadherins* are the main adhesion proteins holding epithelial cells together in sheet arrangement. The removal of calcium disrupts tissue cohesiveness.

b) *Selectins* bind to carbohydrates and belong to the family of C-type lectins, but contrast to cadherins. They participate in the movement of leukocytes circulating in blood toward tissues by extravasation. Homing also permits thymus-derived T cells to home in on peripheral lymph nodes.

3.2 **Ca^{2+}-independent adhesion molecules,** which compose the immunoglobulin (Ig) superfamily and integrins.

a) *Integrins* are the only cell adhesion molecules consisting two subunits: α and β unit. They have a dual function: they blind to the extracellular matrix and the internal cytoskeleton.

b) *Ig superfamily cell adhesion molecules* are generated by the alternative mRNA splicing and have differences in glycosylation. The extracellular segment of a CAM is folded into two to six immunoglobulin-like domains. Ig superfamily CAM, e.g., ICAM (intracellular cell adhesion cell molecule) and VCAM (Vascular cell adhesion molecule) molecules

play important roles in T cell interactions and blinding of leukocytes to activated or resting endothelial cells.

4 **Cell junctions** can be classified as symmetrical and asymmetrical junctions.

- There are four symmetrical junctions.
  a) ***Tight junctions*** contain occluding and claudin, belonging to the protein family of tetraspanins because four segments of protein span the plasma membrane. An additional component is the afadin-nectin protein complex. Tight junctions form a circumferential gasket that controls the paracellular pathway of molecules.
  b) ***Zonula adherens*** **(belt desmosome)** consists of a **plaque** that contains desmoplakin, plakoglobulin, and plakophilin. Cadherins, mainly desmocollins and desmogeins dimers, and the afadin-nectin complex extend from the plaque to the extracellular space. A catenin complex links actin filaments to plaque. It forms a circumferential gasket at the apical region of epithelial cells.
  c) ***Macula adherens*** **(spot desmosome)** are structural comparable with the zinula adherens except that the afadin-nectin and catenin complexes are absent and intermediate filaments (tonofilaments), instead of actin filaments, are attached to plaque.
  d) ***Gap junctions*** are not anchoring junctions as the above 3 junctions. They are communicating junctions connecting adjacents cells. The basic unit of a gap junction is connexon, formed by 6 connexin molecule encircling a central channel.
- There is an asymmetrical junction, i.e., *hemidesmosomes*. They consist of inner membrane **plate**, to which tonofilaments attach, and an outer membrane **plaque**, linked by integrin $\alpha_6\beta_4$ and laminin 5 to the basal lamina.

Table 1-1: Types of the covering epithelium in classification			
Type	**Classification**	**Typical Locations**	**Major Functions**
One cell layer	**Simple squamous**	- Vascular system (endothelium, Fig.1-2) - Body cavities (mesothelium, Fig.1-3) - Bowman's capsule (Fig.1-1)	Exchange, Barrier, Lubrication, Gliding, Selective permeability
	Simple cuboidal # Brush border	- Small ducts of exocrine gland (Fig 1-4) - Wall of thyroid follicle, (Fig.1-5) - Ependyma & Covering surface of ovary as germinal epithelium (Fig.1-6) - Proximal renal tubules (Fig.1-7)	Absorption, conduit, Secretion barrier Absorption & secretion
	Simple columnar # Brush border # Cilia	- Gallbladder (Fig.1-8) - Large collecting ducts (Fig.1-9) - Small intestine (Fig.1-10) - Uterine tube (Fig.1-11)	Absorption & secretion
	Pseudostratified Columnar # Neuroepithelium # Cilia & goblet cells # Stereocilia	Olfactory epithelium (sense of smell, Fig.1-14) - Trachea & bronchial trees (Fig.1-12) - Pharyngeal tonsils Epididymis (Fig.1-13)	Receptors for the special sense Secretion & conduit Absorption & conduit
More than one cell layers	**Stratified squamous** # Moist type # Keratinized type	Esophagus, Vagina (Fig.1-15) Epidermis (Fig.1-16)	Barrier, Protection
	Stratified cuboidal	Sweat gland ducts (Fig.1-17)	Barrier, conduit
	Stratified columnar # Goblet cells	Largest ducts of exocrine glands (Fig.1-18) Conjunctiva (Fig.1-19)	Barrier, conduit Barrier, secretion
	Transitional epithelium or uroepithelium (some text books referred as pseudostratified)	Renal calyces (Fig.1-20) Ureter Bladder	Barrier, distensible property

Table 1-2: Modification of the apical and baso-lateral domain of the epithelial cell.			
Epithelial domain	**Structure**	**Feature**	**Function**
Apical	**1. Microvilli**	# Fingerlike projections, 1 μm long that extend into a lumen. 1. Glycocalyx coat 2. F- actin bundles as a core 3. Constitute the brush border of renal proximal tubules (Fig.1-7) and striated bored of intestinal absorptive cells (Fig.1-10)	Increase the cell's surface Digestion, Absorption
	2. Stereocilia	# Very long microvilli in the epididymis (Fig.1-13), vas deferens of the male reproductive tract and air cells of the inner ear.	Absorption
	3. Cilia	# Actively motile processes 5-10 μm long from epithelia, e.g., tracheobronchial (Fig.1-12) and oviduct (Fig.1-11) epithelium. 1. A core longitudinally arranged microtubules (axoneme,9+2 doublet microtubules)	Propel substances a long their surfaces.
		2. The basal body: a cylindrical structure at the base of each cilium and consists of nine triple microtubules arranged radially in the shape of a pinwheel (9+0 triplet microtubules)	Basal bodies originate cilia and resemble the centrioles.
Lateral	**1. Junction complex** Consists 3 structures in TEM	An intricate arrangement of membrane-associated structure. It corresponds to the terminal bar in the LM.	Cell-to-cell attachment.
	i. The tight junction (zonula occludens)	# They extend along the entire circumference of the cell. The outer leaflets of the apposed cell membranes fuse with each other.	Preventing materials from taking the paracellular route between the connective tissue and the lumen.

Lateral	ii. The intermediate junction (belt desmosome; zonula adherens)	# They are located just basal to the tight junctions and are distinguished by the presence of E- cadherins, transmembrane glycoproteins. Intracellularly, actin filaments form a meshwork that attached to the E-cadherins by the outer molecules.	Cell-to-cell adherence, as structurally supporting junction.
	iii. A desmosome (macula adherens)	# They possess the desmogleins and E-cadherins transmembrane glycoproteins, whose cytoplasmic ends are associated with a plaque composed of desmoplakins. Intermediate filaments, forming hairpin loops, enter and exit the plaque.	Cell-to-cell attachment and adherence as the spotting.
	2. The gap junction (communicating junction; nexus)	# Ions and small molecules are permitted to pass between adjoining cells. They couple adjacent cells metabolically and electrically.	Communication between cells.
Basal	**1. The basal lamina**	An extracellular supporting structure 20 to 100 nm thick that is visible only by TEM. It is produced by the epithelium resting upon and it is composed mainly of type IV collagen, laminin, entactin and proteoglycans (rich in heparin sulfate). There are two zones: lamina lucida or rara and lamina densa. **Basal lamina + underlying reticular lamina = the basement membrane (in LM).**	Supportive structure and barrier between epithelial layer and the underlying connective tissue.
	2. Hemidesmosome	It resembles half of a desmosome and present on the basal surface of basal cells in certain epithelia, e.g., tracheal and stratified squamous epithelium. It consists of (1) a dense cytoplasmic plaque, which is linked via transmembrane receptor proteins (integrins) to laminins in the basal lamina (2) Keratin filaments or tonofilaments in the cell terminate in the hemidesmosome plaque, allowing the junction to link the cytoskeleton with the extracellular matrix.	Mediating the adherence of epithelial cells to the underling basal lamina.

2. Glandular epithelium

They originate from a covering epithelium that penetrates the connective tissue and forms secretory units. Therefore, a gland consists of

i. functional portion (parenchymal tissue) and,

ii. ductal epithelial epithelium, which is separated by a basal lamina from supporting tissue elements (stroma).

It has two types of glandular epithelium, exocrine and endocrine gland. An organ could be consisted of both types of glandular epithelium, called mixed exo-endocrine glands.

1. Exocrine glands secret their products onto body surfaces through a duct.
2. Endocrine glands are ductless and secrete their products, hormones into the interstitial spaces before entering the blood circulation. They are mostly surrounded by fenestrated capillaries.

Some textbook mentioned paracrine glands secrete their products into the local extracellular space. It could be classified as the endocrine gland.

1. **Classification of the glandular epithelium.**
    1. Exocrine glands base on the number of secretory cells.
        i) Unicellular glands are composed of a single cell (e.g. goblet cells, Fig.1-10, 12 &19).
        ii) Multicellular glands, e.g., salivary glands, sweat gland, sebaceous gland, etc.

Classification of multicellular glands is based on two criteria:

- They are classified according to duct branching as **simple glands** (duct does not branch) or **compound glands** (duct branches).
- They are further classified according to the **shape of the secretory unit** as **acinar** or **alveolar** (sac-like or flask-like) or tubular (straight, coiled, or branched).

a) Classification of multicellular glands is based on the location of connective tissue capsule and ducts in the gland.

i) A connective tissue capsule may surround the gland, or septa of connective tissue may divide the gland into **lobes** and smaller **lobules** (Fig.1-27).

ii) Glands may have ducts between lobes (**interlobar duct** Fig.1-18), within lobes (**intralobar**), between lobules (**interlobular duct**, Fig.1-27), or within lobules (**intralobular ducts**, Fig. 1-25, 26, 29), such as striated and intercalated ducts.

b) **Classification of multicellular glands is base the nature of their products.**

i) **Mucus** is a viscous material that usually protects or lubricates cell surfaces, i.e., sublingual salivary gland (Fig.1-28). It is rich in glycoproteins.

ii) **Serous** secretions are watery and often rich in enzymes, i.e., parotid salivary gland (Fig.1-29).

iii) **Mixed** secretions contain both mucous and serous components, e.g., submandibular salivary gland (Fig.1-26).

iv) **Cytogenic cell** secretions are spermatic cells via male genital ducts, i.e., seminiferous tubules (Fig.1-30) in testis.

c) **Mechanisms of the secretion of secretory cells.**

i) In **merocrine** secretion, the product is released by **exocytosis**. An example is the secretion of zymogen granules by exocrine pancreas (Fig.1-25), of sweat by eccrine sweat glands (Fig.1-17).

ii) In **apocrine** secretion, the release of the secretory products involves **partial loss of the apical portion of the cell**. An example is the secretion of lipids by secretory cells of the mammary gland, Fig.1-27, and the ceruminous glands of the external auditory meatus.

iii) In **holocrine** secretion, the secretory product constitutes the **entire cell and its product**. An example is the sebaceous glands (Fig.1-23) of the skin, which produce a secretion called **sebum.**

2. Endocrine glands may be **unicellular** (e.g., individual endocrine cell in gastro-intestinal and respiratory epithelia) or **multicellular** (e.g., adrenal gland, parathyroid gland and thyroid gland, Fig.1-31). They commonly store the secretions which they synthesize and release after stimulation by chemical or electrical signals.
3. Exocrine and endocrine (mixed exo-endocrine) glands can be found together (for example, in the pancreas, Fig.1-25, and in the testis, Fig.1-30)

Table 1-3: Classification of Multicellular glands			
Classification		Typical location	Features
Simple	tubular	Large intestine: intestinal gland of the colon (Fig. 1-21)	Secretory portion is straight formed by the secretory cells (goblet cells)
	coiled tubular	Skin: eccrine sweat gland (Fig. 1-17) in the dermis	Coiled tubular structure is composed of a secretory portion.
	branched tubular	Mucus-secreting glands of the pylorus (Fig. 1-22)	Branched tubular glands with wide secretory portion.
	Acinar or alveolar gland	Skin: sebaceous glands (Fig.1-23), or in urethra as paraurethral & periurethral glands	Simple acinar glands are formed as by a single layer of secretory cells. In sebaceous glands, the terminal secretory portion is divided by partitions into sacs called acini or alveoli.
	branched acinar	Mucus-secreting glands of cardia of the stomach	Branched acinar glands with secretory portions; short, single-duct portion opens directly into the lumen
Compound	tubular	Duodenum: Submucosal glands of Brunner (Fig.1-24)	Compound tubular glands with coiled secretory portions
	acinar	Pancreas: exocrine Portion (Fig.1-25)	Compound acinar glands with alveolar-shaped secretory units.
	tubulo-acinar	Submandibular salivary gland (Fig.1-26) Mammary gland (Fig.1-27)	Compound tubule-acinar glands can have both mucous branched tubular and serous branched acinar units; they have serous end-caps (demilunes), Fig.1-26.

Clinical correlations

1. **Epithelial metaplasia** is a reversible conversion, one mature epithelial cell type to another mature epithelial cell type. The most common epithelial metaplasia is **columnar-to- squamous** and occurs in the glandular epithelium, where the columnar cells become replaced by stratified squamous epithelium. Squamous-to- columnar epithelial metaplasia may occur. For example, as a result of gastroesophageal reflux, the epithelial lining of the esophagus is known as Barrett's esophagus.
2. **Immotile Cilia syndrome** or primary ciliary dyskinesia (PCD) is one of hereditary (autosomal recessive) disorders and affect the function of cilia. Motile cilia covering the epithelium of the respiratory tract are responsible for the clearance of the airway. Failure of the mucociliary transport system occurs in **Katagener's syndrome**, which is caused by a structural abnormality that results inabsence of dynein arms.

   Note: There are two types of cilia

   i. **Multiple motile cilia** function to coordinate fluid or cargo flow on the surface of an epithelium. They are cells projections originating from basal bodies anchored by rootlets to apical portion of the cytoplasm. The trachea and the oviduct are lined by ciliated epithelial cells.

   ii. **Single or primary non-motile cilium**. The significant aspects of primary cilium are: (i) it function as sensor that provides the ell with information about the surrounding external environment, (ii) it participates in the early stages of embryonic patterning leading to organogenesis, (iii) the position of the single cilium, called kinocilium, of the hair cell of the organ of Corti in the inner ear determines the correct polarity of the adjacent actin-containing stereocilia, essential for maintaining body balance and hearing.
3. Malignant tumors of epithelial origin are called **carcinoma**, if they derived from glandular epithelial tissue are called **adenocarcinoma**.

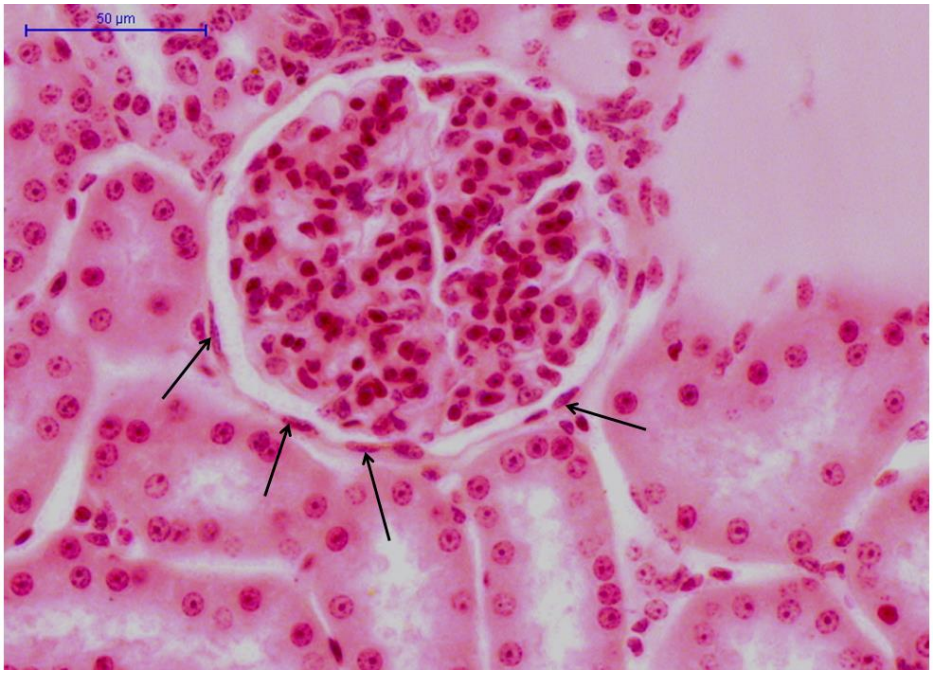

Figure 1-1: Simple squamous epithelial cells (arrows) from the parietal layer of Bowman's capsule in a renal corpuscle.

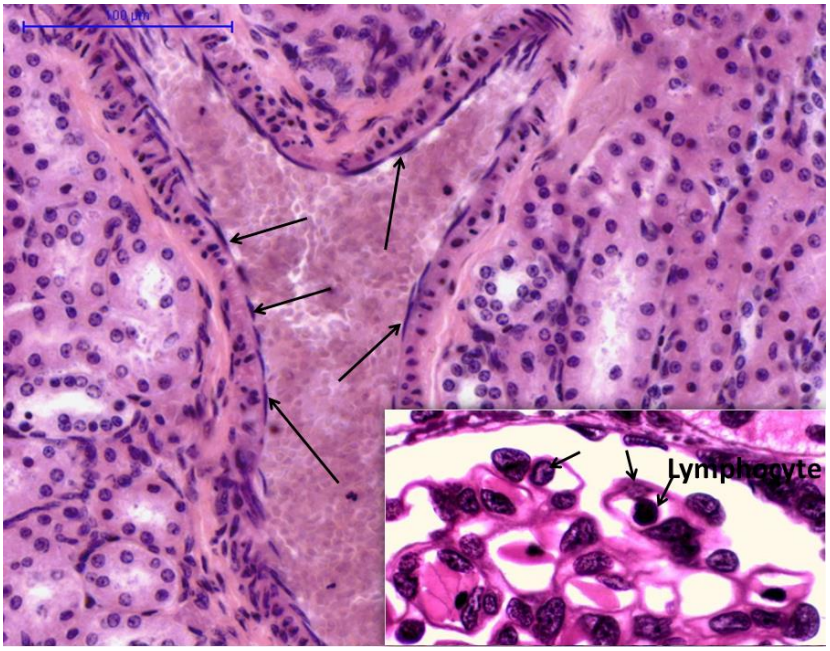

Figure 1-2: Simple squamous epithelial cells (arrows) that line the lumen of blood vessels. This type of the epithelium is always called endothelium.

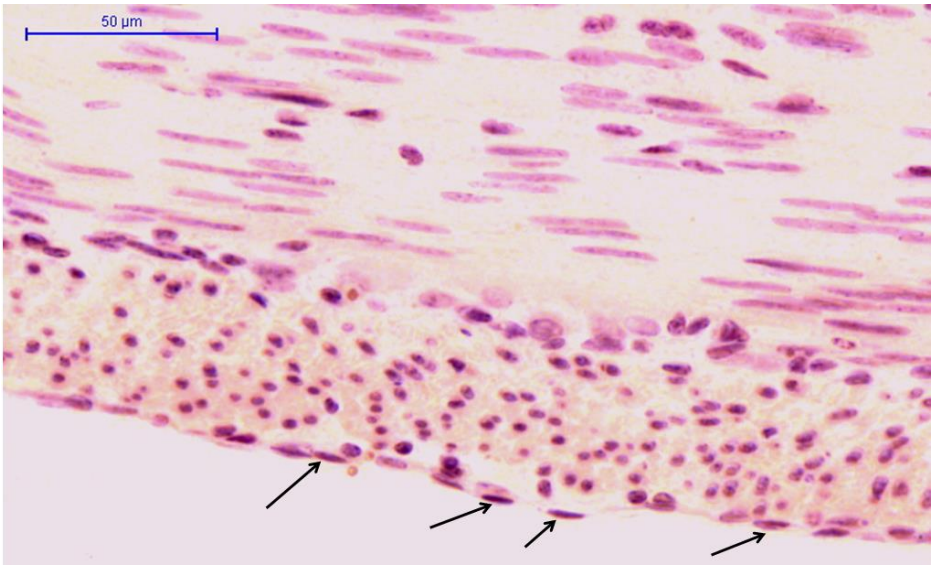

Figure 1-3: Simple squamous epithelium (arrows) of the serosa (or serous membrane) of the small intestine. This type of the epithelium is always called the mesothelium.

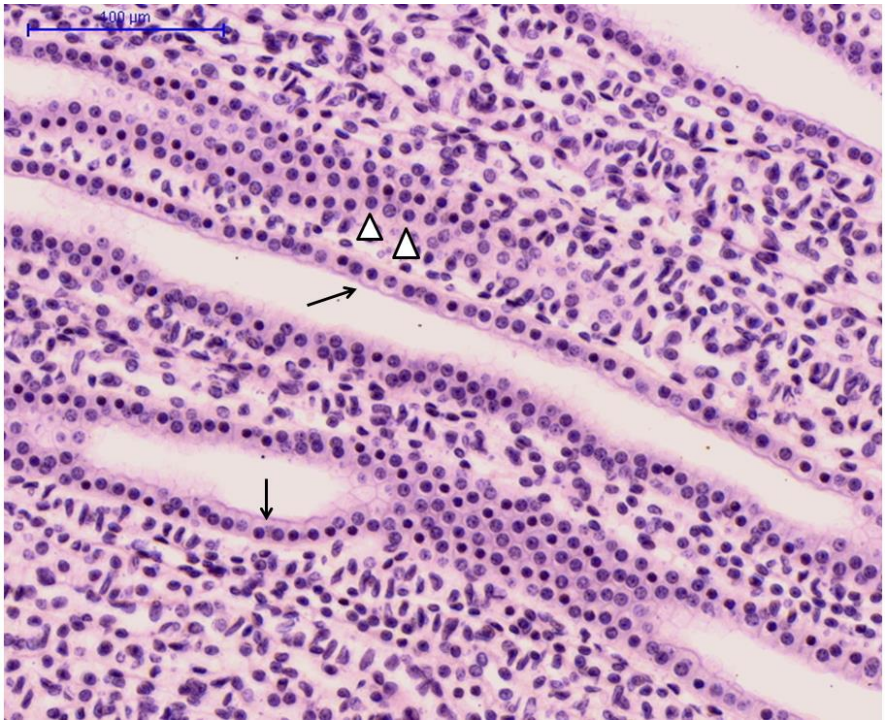

Figure 1-4: Simple cuboidal epithelium of renal collecting tubules in the longitudinal (arrows) and crossed (arrow heads) section.