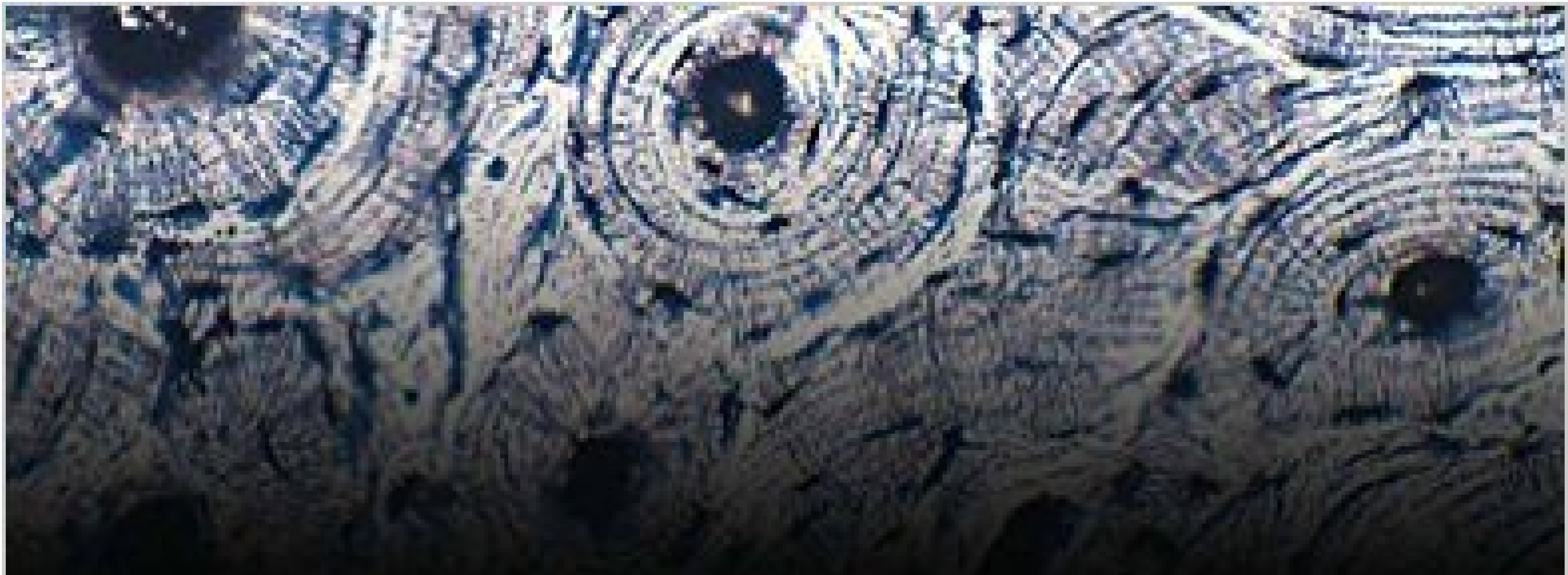
Junqueira's Basic Histology Text & Atlas (14th ed.)

Anthony L Mescher
Indiana University Bloomington



JUNQUEIRA'S Basic Histology

Text and Atlas

Fourteenth Edition

Anthony Mescher

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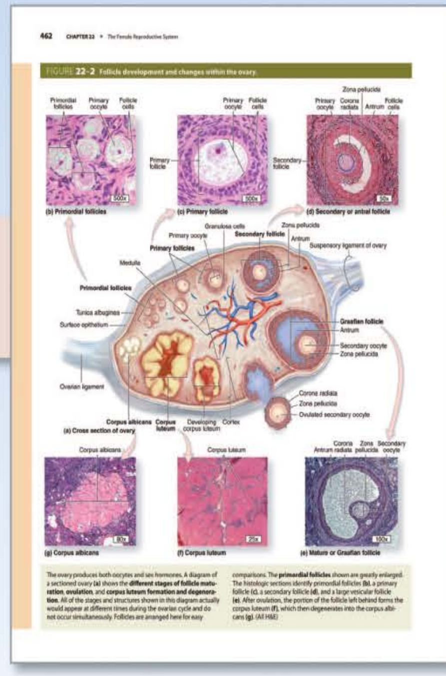

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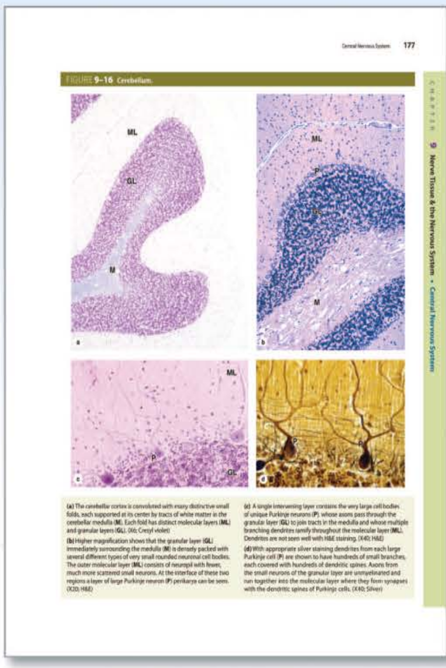

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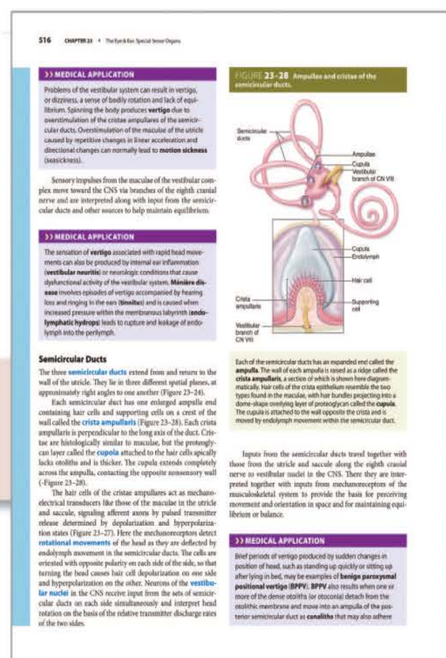

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FOURTEENTH EDITION

Junqueira's Basic Histology

TEXT AND ATLAS

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Junqueira's Basic Histology, Fourteenth Edition

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Preface

With this 14th edition *Junqueira's Basic Histology* continues as the preeminent source of **concise yet thorough** information on human tissue structure and function. For nearly forty-five years this educational resource has met the needs of learners for a well-organized and concise presentation of **cell biology and histology** that integrates the material with that of **biochemistry, immunology, endocrinology, and physiology** and provides an excellent foundation for subsequent studies in **pathology**. The text is prepared specifically for students of medicine and other health-related professions, as well as for advanced undergraduate courses in tissue biology. As a result of its value and appeal to students and instructors alike, *Junqueira's Basic Histology* has been translated into a dozen different languages and is used by medical students throughout the world.

A major change in this edition is the inclusion of **Self-Assessment Questions** with each topic/chapter. Many of these questions were used in my courses, but others are taken or modified from a few of the many excellent review books published by McGraw-Hill/Lange for students preparing to take the U.S. Medical Licensing Examination. These include *Histology and Cell Biology: Examination and Board Review*, by Douglas Paulsen; *USMLE Road Map: Histology*, by Harold Sheedlo; and *Anatomy, Histology, & Cell Biology: PreTest Self-Assessment & Review*, by Robert Klein and George Enders. The use here of questions from these valuable resources is gratefully acknowledged. Students are referred to those review books for hundreds of additional self-assessment questions. As with the last edition, each chapter also includes a **Summary of Key Points** designed to guide the students concerning what is clearly important and what is less so. **Summary Tables** in each chapter organize and condense important information, further facilitating efficient learning.

Each chapter has been revised and shortened, while coverage of specific topics has been expanded as needed. Study is facilitated by modern page design. Inserted throughout each chapter are more numerous, short paragraphs that indicate how the information presented can be used medically and which emphasize the foundational relevance of the material learned.

The **art** and other figures are present in every chapter, with the goal to simplify learning and integration with related material. The McGraw-Hill medical illustrations now used throughout the text, supplemented by numerous animations in the electronic version of the text, are the most useful, thorough, and attractive of any similar medical textbook. Electron and light micrographs have been replaced throughout the book as needed, and again make up a **complete atlas of cell, tissue, and organ structures** fully compatible with the students' own collection of glass or digital slides. A **virtual microscope** with over 150 slides of all human tissues and organs is available: http://medsci.indiana.edu/junqueira/virtual/junqueira.htm.

As with the previous edition the book facilitates learning by its **organization**:

- An opening chapter reviews the **histological techniques** that allow understanding of cell and tissue structure.
- Two chapters then summarize the structural and functional organization of **human cell biology**, presenting the cytoplasm and nucleus separately.
- The next seven chapters cover the **four basic tissues** that make up our organs: epithelia, connective tissue (and its major sub-types), nervous tissue, and muscle.

- Remaining chapters explain the organization and functional significance of these tissues in **each of the body's organ systems**, closing with up-to-date consideration of cells in the eye and ear.

For additional review of what's been learned or to assist rapid assimilation of the material in *Junqueira's Basic Histology*, McGraw-Hill has published a set of 200 full-color ***Basic Histology Flash Cards***, Anthony Mescher author. Each card includes images of key structures to identify, a summary of important facts about those structures, and a clinical comment. This valuable learning aid is available as a set of actual cards from Amazon.com, or as an app for smart phones or tablets from the on-line App Store.

With its proven strengths and the addition of new features, I am confident that *Junqueira's Basic Histology* will continue as one of the most valuable and most widely read educational resources in histology. Users are invited to provide feedback to the author with regard to any aspect of the book's features.

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Contents

The Nucleus ASSESS YOUR KNOWLEDGE

1. Which of the following facilitates breakdown of the nuclear envelope during the onset of mitosis?
   a. Disassembly of nucleosomes in the associated constitutive heterochromatin
   b. Increased export of material by the nuclear pore complexes into the perinuclear space
   c. Phosphorylation of lamin subunits by a cyclin-dependent kinase (CDK)
   d. Activities triggered at a restriction point late in G_1
   e. The activity of proteasomes

2. Binding of histone H1 proteins to importins is important for which of the following?
   a. Transport through the nuclear pores complexes
   b. Properly directed vesicular transport through the Golgi apparatus
   c. Transport from the granular part of the nucleolus
   d. Further binding to the "linker DNA" and proper assembly of nucleosomes
   e. Phosphorylation of cyclins

3. Which of the following is a region of chromatin that is well developed in large neurons active in protein synthesis?
   a. Heterochromatin
   b. The nucleolus
   c. The Nissl substance (neuronal RER)
   d. The Barr body
   e. The nucleosome

4. Which of the following is found during meiosis but not mitosis?
   a. Chromatids
   b. Polar microtubules
   c. Metaphase
   d. Synapsis
   e. Cytokinesis

5. Transitions in the cell cycle from one phase to the next are regulated by protein kinases whose activity depends on what other proteins?
   a. Tumor suppressors
   b. Cyclins
   c. Actins
   d. Lamins
   e. Importins

6. Mitotic figures visible in a tissue section from the lining of the small intestine are most likely to belong to which of the following categories?
   a. Terminally differentiated cells
   b. Partially differentiated cells
   c. Blood cells
   d. Stem cells
   e. Progenitor cells

7. Key differences between apoptotic and necrotic cell death include which of the following?
   a. Apoptotic cells do not release factors that induce inflammation.
   b. Necrosis does not trigger inflammation.
   c. Apoptosis does not utilize intracellular proteases.
   d. Apoptosis usually follows lethal physical damage to a cell.
   e. Necrosis is involved in formation of some organs during embryonic development.

8. A 29-year-old woman presents with a 101°F fever, pericardial effusions and Libman-Sachs endocarditis, arthralgia, and facial rash across the malar region ("butterfly rash") that is accentuated by sun exposure. Laboratory tests show creatine 1.7 mg/dL (normal 0.5-1.1 mg/dL), high titers of antinuclear autoantibodies (ANA), Smith antigen, and antinucleosome antibodies in the blood. Which one of the following is most likely to be directly affected by the disruption of nucleosomes in this patient?
   a. Packaging of genetic material in a condensed form
   b. Transcribing DNA
   c. Forming pores for bidirectional nuclear-cytoplasmic transport
   d. Forming the nuclear lamina
   e. Holding together adjacent chromatids

9. A 32-year-old man and his 30-year-old wife are referred for a reproductive endocrinologist infertility (REI) consult after 2 years of "trying to get pregnant." He is diagnosed with oligozoospermia. Ejaculated mature sperm are collected and undergo genetic analysis. Using gene linkage analysis, his REI specialist determines that he has aberrations in spermatogenic meiotic recombination, including both diminished frequency and suboptimal location, resulting in high frequency of aneuploid sperm. In explaining the diagnosis, she explains meiosis and recombination attributing the problem to a specific phase of the meiosis. Which part of meiosis is most closely associated with recombination?
   a. Metaphase I
   b. Anaphase I/Telophase I
   c. Prophase I
   d. Prophase II
   e. Anaphase II/Telophase II

10. A newborn boy is diagnosed with Apert syndrome. He has craniosynostosis, hypoplasia of the middle part of the face with retrusion of the eyes, and syndactyly that includes fusion of the skin, connective tissue, and muscle of the first, middle, and ring fingers with moderate fusion of those digits. There is very limited joint mobility past the first joint. Which one of the following is most likely *decreased* in cells of the interdigital regions of the developing hand of this newborn child?
    a. Random DNA degradation
    b. Inflammation
    c. Cell swelling
    d. Bcl-2
    e. DNA degradation by endonucleases

Answers: 1c, 2a, 3b, 4d, 5b, 6e, 7a, 8a, 9c, 10e

CHAPTER 4 Epithelial Tissue

Despite its complexity, the organs of the human body are composed of only **four basic tissue types:** epithelial, connective, muscular, and nervous tissues. Each tissue is an assemblage of similarly specialized cells united in performing a specific function. The basic tissues, each containing extracellular matrix (ECM) as well as cells, associate with one another in the variable proportions and morphologies characteristic of each organ. The main features of the basic tissue types are summarized in Table 4–1.

Connective tissue is characterized by cells producing very abundant ECM; muscle tissue is composed of elongated cells specialized for contraction and movement; and nervous tissue is composed of cells with long, fine processes specialized to receive, generate, and transmit nerve impulses. Most organs can be divided into the **parenchyma**, which is composed of the cells responsible for the organ's specialized functions, and the **stroma**, the cells of which have a supporting role in the organ. Except in the brain and spinal cord, the stroma is always connective tissue.

Epithelial tissues are composed of closely aggregated polyhedral cells adhering strongly to one another and to a thin layer of ECM, forming cellular sheets that line the cavities of organs and cover the body surface. Epithelia (Gr. *epi*, upon + *thele*, nipple) line all external and internal surfaces of the body and all substances that enter or leave an organ must cross this type of tissue.

The principal functions of epithelial tissues include the following:

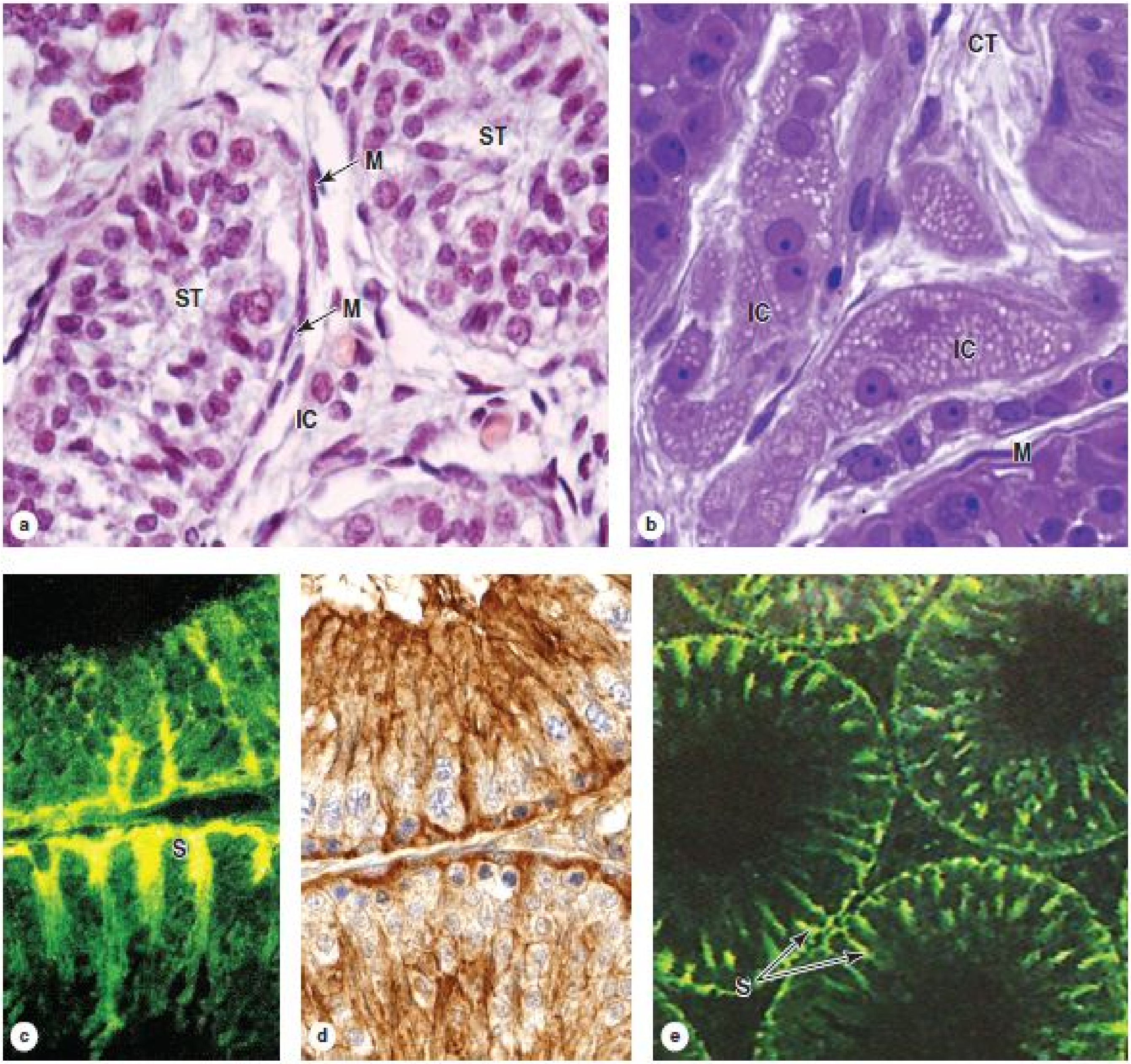
- Covering, lining, and protecting surfaces (eg, epidermis)
- Absorption (eg, the intestinal lining)
- Secretion (eg, parenchymal cells of glands)

Specific cells of certain epithelia may be contractile (myoepithelial cells) or specialized sensory cells, such as those of taste buds or the olfactory epithelium.

TABLE 4–1 Main characteristics of the four basic types of tissues.

Tissue	Cells	Extracellular Matrix	Main Functions
Epithelial	Aggregated polyhedral cells	Small amount	Lining of surface or body cavities; glandular secretion
Connective	Several types of fixed and wandering cells	Abundant amount	Support and protection of tissues/organs
Muscle	Elongated contractile cells	Moderate amount	Strong contraction; body movements
Nervous	Elongated cells with extremely fine processes	Very small amount	Transmission of nerve impulses

FIGURE **21–4** **Interstitial cells and Sertoli cells.**



(a) Seminiferous tubules (**ST**) are surrounded by stroma containing many interstitial cells (**IC**), typically located near capillaries, which secrete androgens. The seminiferous tubule wall consists of a unique germinal epithelium composed of columnar Sertoli cells and dividing spermatogenic stem cells. Seen around the seminiferous tubules are myoid cells (**M**) with elongated nuclei, the contractions of which help move fluid and mature sperm in the tubules. (X400; H&E)

(b) A plastic section shows lipid droplets filling the cytoplasm of the clumped interstitial cells (**IC**), or Leydig cells, in the connective tissue (**CT**) between tubules. Such cytoplasm is typical of steroid-secreting endocrine cells and here indicates cells actively secreting testosterone. The epithelium of a nearby seminiferous tubule is immediately surrounded by myoid cells (**M**). (X400; PT)

(c) Immunohistochemistry of a seminiferous tubule wall with antibodies against prosaposin, a glycoprotein abundant in Sertoli cells. The yellow fluorescent stain indicates the tall columnar shape of Sertoli cells (**S**) and the dendritic nature of their apical ends. Sertoli cells support all spermatogenic cells physically and metabolically, phagocytize debris, and have endocrine roles affecting spermatogenesis and fetal development of the male reproductive tract. (400X; Immunofluorescence)

(d) Immunohistochemistry of the seminiferous tubule with the same antibodies labeled with peroxidase shows the tall Sertoli cells in brown. This bright-field preparation also shows the close association of the Sertoli cells with the numerous spermatogenic cells, whose nuclei are stained with hematoxylin. (400X; Immunoperoxidase & hematoxylin)

(e) Lower magnification of the same preparation as part c shows the distribution and density of Sertoli cells (**S**) in the seminiferous tubules. (200X; Immunofluorescence)

(Figure 21–4c-e used, with permission, of Dr Richard Sharpe and Chris McKinnell, University of Edinburgh, MRC Centre for Reproductive Health, UK.)

SAMPLE

The Male Reproductive System ASSESS YOUR KNOWLEDGE

1. Which of the following accurately describes spermiogenesis?
   a. Occurs before puberty
   b. Involves stem cells, meiosis, and spermatogenesis
   c. Involves cytodifferentiation of early spermatids
   d. Occurs in diploid cells
   e. Results in the formation of primary spermatocytes

2. A man with a pituitary gonadotrophic tumor causing hyposecretion of follicle-stimulating hormone (FSH) is most likely to exhibit which condition?
   a. No symptoms, since he has no ovarian follicles
   b. Loss of libido (sex drive)
   c. Low serum testosterone levels
   d. Low sperm count
   e. Prostatic hypertrophy

3. Interstitial cells of Leydig have an important function in male gamete production. Because of this function, which of the following organelles is abundant within these cells?
   a. Lysosomes
   b. Smooth endoplasmic reticulum
   c. Peroxisomes
   d. Polyribosomes
   e. Golgi complexes

4. While studying a germ cell line developed from a patient's testicular biopsy, the researcher notes that colchicine-treated cells blocked in metaphase have 46 chromosomes. From which of the following regions of the male genital tract would you expect these cells to have originated?
   a. Within the rete testis
   b. At the basal lamina of the seminiferous tubule
   c. In the middle region of the germinal epithelium
   d. Within the adluminal compartment of the seminiferous tubule
   e. Within the straight tubules

5. Which of the following organs is normally characterized by the accumulation of corpora amylacea with increasing age?
   a. Prostate
   b. Seminal vesicles
   c. Bulbourethral (Cowper) glands
   d. Epididymis
   e. Ductus (vas) deferens

6. Within the male reproductive tract, stereocilia project from cells lining which of the following regions?
   a. Rete testis
   b. Seminiferous tubules
   c. Ampulla of the ductus deferens
   d. Epididymis
   e. Penile urethra

7. As sperm pass through the male genital ducts, proteins and low molecular weight products are added from several sources producing semen. Which of the following provides a nutritive, fructose-rich secretion?
   a. Interstitial cells of Leydig
   b. Bulbourethral (Cowper) glands
   c. Prostate gland
   d. Epididymis
   e. Seminal vesicles

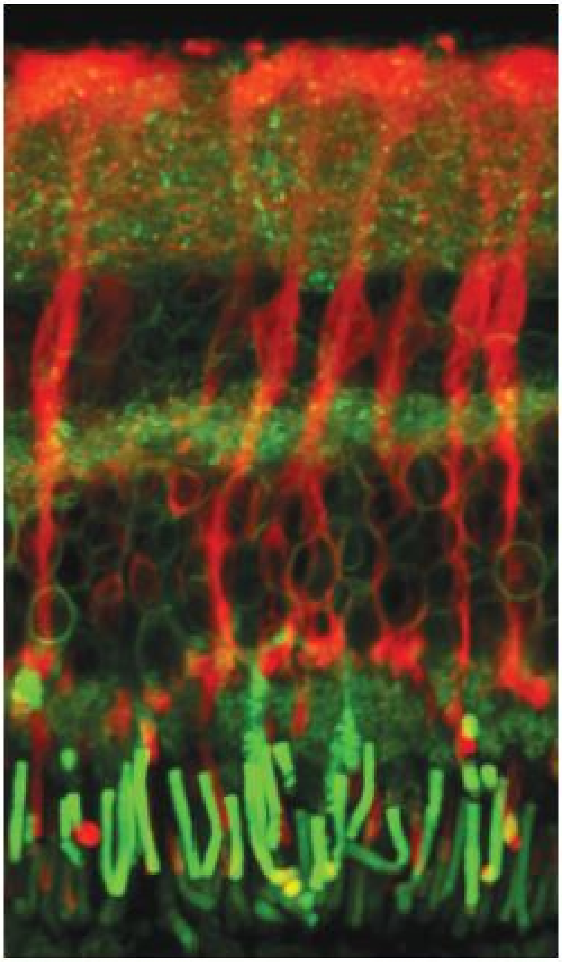
8. A 20-year-old man contracts cholera during a long tour of military duty in a remote, completely undeveloped region. After a 5-day period of severe diarrhea and treatment, he gradually recovers and slowly returns to work. He is married 3 years later but after a few years of trying to conceive a child, semen analysis reveals that his sperm are few in number and malformed, and blood tests show a high titer of antibodies against sperm antigens. The causative agent of cholera, *Vibrio cholera*, secretes a toxin that interferes with tight (occluding) junctions. What cells in the gonad are the likely target of this toxin in the male reproductive system?
   a. Spermatogonia
   b. Sertoli cells
   c. Myoid cells
   d. Interstitial cells of Leydig
   e. Differentiating spermatozoa

9. A 29-year-old man presents with testicular pain and a burning sensation during urination. Tests reveal the presence of *Neisseria gonorrhea* and penicillin is prescribed. Gonorrhea often produces acute or chronic inflammation of the testes and frequently involves the channels that connect the testis to the epididymis. What is the name of these channels?
   a. The mediastinum testis
   b. The rete testis
   c. Efferent ductules
   d. The straight tubules (tubuli recti)
   e. The seminiferous tubules

10. A 39-year-old man undergoing an extensive series of tests for infertility is found to have a genetic mutation that prevents formation of a functional synaptonemal complex during meiosis, causing almost complete failure of sperm formation. Which cells would be directly affected by this mutation?
    a. Primary spermatocytes
    b. Spermatogonia
    c. Secondary spermatocytes
    d. Spermatids
    e. Cells undergoing spermiogenesis

Answers: 1 c, 2d 3b, 4b, 5a, 6d 7e, 8b, 9c, 10a

FIGURE **23–16** **Müller cells.**



Müller cells are large glial cells unique to the retina, which are critical for retinal function by providing trophic and metabolic support for adjacent neurons, regulating homeostasis and synaptic activity, and helping to organize retinal components structurally. The attenuated and diffuse nature of Müller cells makes these cells difficult to study microscopically in most routine preparations of retina. This confocal light microscope image of a section of living guinea pig retina, with its layers named as in the previous figure, shows the large Müller cells in red. Axons and dendrites, abundant in the plexiform layers, and the outer segments of the photoreceptor cells appear green.

Müller cells extend through the full thickness of the retina, with fine lateral processes contacting all adjacent neuronal cell bodies, synapses, and blood vessels. At a level just beyond the layer of photoreceptor cell nuclei, Müller cells are sealed to the photoreceptor cells by zonula adherens junctions, forming the outer limiting layer (OLL). A few long Müller cell processes extend beyond this layer, into the layer of rods and cones (RCL). The nerve fiber layer (NFL) is very thin in the area shown here and the pigmented epithelium is not stained. (X400; Vital dyes Mitotracker Orange [red] & FM-43 for synaptic membranes [green])

(With permission, from Dr. Andreas Reichenbach, Paul Flechsig Institute of Brain Research, University of Leipzig, Germany.)

the INL. A few scattered microglial cells occur throughout the neural retina.

Rod Cells

The human retina contains on average 92 million **rod cells**. They are extremely sensitive to light, responding to a single photon, and allow some vision even with light low levels, such as at dusk or nighttime. Rod cells are thin, elongated cells (50 μm × 3 μm), composed of two functionally distinct segments (Figure 23–17a). The **outer segment** is a modified primary cilium, photosensitive and shaped like a short rod; the inner segment contains glycogen, mitochondria, and polyribosomes for the cell's biosynthetic activity.

The rod-shaped segment consists mainly of 600 to 1000 flattened **membranous discs** stacked like coins and surrounded by the plasma membrane (Figure 23–17). Proteins on the cytoplasmic surface of each disc include abundant **rhodopsin** (or **visual purple)** which is bleached by light and initiates the visual stimulus. Between this outer segment and the cell's inner segment is a constriction, the **connecting stalk**, which is part of the modified primary cilium arising from a basal body (Figure 23–17).

The membranous discs form by repetitive in-folding of the plasma membrane near the connecting stalk and insertion of rhodopsin and other proteins transported there from the inner segment. In rod cells the newly assembled discs detach from the plasma membrane and are displaced distally as new discs form. Eventually the discs arrive at the end of the rod, where they are shed, phagocytosed, and digested by the cells of the pigmented epithelium (Figure 23–13). Each day approximately 90 membranous discs are lost and replaced in each rod, with the process of assembly, distal movement, and apical shedding taking about 10 days.

Cone Cells

Less numerous and less light-sensitive than rods, the 4.6 million **cone cells** in the typical human retina produce color vision in adequately bright light. There are three morphologically similar classes of cones, each containing one type of the visual pigment **iodopsin** (or photopsins). Each of the three iodopsins has maximal sensitivity to light of a different wavelength, in the red, blue, or green regions of the visible spectrum, respectively. By mixing neural input produced by these visual pigments, cones produce a color image.

Like rods cone cells (Figure 23–17a) are elongated, with outer and inner segments, a modified cilium connecting stalk, and an accumulation of mitochondria and polyribosomes. The outer segments of cones differ from those of rods in their shorter, more conical form and in the structure of their stacked membranous discs, which in cones remain as continuous invaginations of the plasma membrane along one side (Figure 23–17a). Also, newly synthesized iodopsins and other membrane proteins are distributed uniformly throughout the cone outer segment and, although iodopsin turns over, discs in cones are shed much less frequently than in rods.

The Eye & Ear: Special Sense Organs SUMMARY OF KEY POINTS

Eye

- The eye has three tunics: the sclera and cornea form the outer fibrous tunic; the middle vascular layer (or uvea) consists of the choroid, ciliary body, and iris; and the retina forms the inner tunic.
- The transparent cornea consists of an anterior stratified squamous epithelium on Bowman membrane, a thick avascular stroma, and an inner endothelium on Descemet membrane.
- Aqueous humor is secreted by ciliary processes into the posterior chamber, flows through the pupil into the anterior chamber, and is drained by the scleral venous sinus in the limbus.
- The iris stroma contains melanocytes and posteriorly has smooth muscle fibers of the sphincter pupillae muscle and the myoepithelial cells forming the dilator pupillae muscle.
- The lens is a unique avascular tissue composed of long lens fibers, covered on its anterior side by cuboidal lens epithelium, and surrounded by a thick acellular layer called the lens capsule.
- The lens is suspended behind the iris and its central pupil by the ciliary zonule of fibrillin fibers produced by epithelial cells covering the encircling ciliary body.
- The retina has the two major parts derived from the embryonic optic cup: the pigmented epithelium next to the vascular choroid layer and the thicker neural retina.
- Cells of the pigmented epithelium absorb scattered light, form part of a blood-retina barrier, regenerate 11-*cis*-retinal, phagocytose shed discs from rods, and support the rod and cone cells.
- Rod cells are photoreceptors detecting light intensity with short rod-shaped outer segments; less numerous cone cells, with conical outer segments, are receptors for the primary colors (light of different wavelengths).
- Rods have stacked membrane discs in which the membranes are densely packed with the protein rhodopsin with bound retinal.
- Photons of light convert 11-*cis*-retinal to all-*trans*-retinal, causing rhodopsin to release the retinal (bleaching), and activate the adjacent G protein transducin, which causes a nerve impulse.
- In the neural retina the rod and cone layer (RCL) is nearest to the retina pigmented epithelium and near the outer nuclear layer (ONL) which contains the cell bodies of these photoreceptors.
- An outer plexiform layer (OPL) contains the photoreceptor's axons connected in synapses with dendrites of various integrating neurons whose cell bodies form the INL.
- Axons from cells in the INL form synapses in the inner plexiform layer (IPL) with neurons of ganglionic layer (GL), which send axons through the nerve fiber layer (NFL) to the optic nerve.
- Eyelids are lined by conjunctiva, a stratified columnar epithelium with goblet cells, which also covers the anterior part of the sclera and is continuous with the corneal epithelium.
- Lacrimal glands continuously produce the tear film that drains into the nasal cavity via the ducts of the lacrimal apparatus.

Ear

- The acoustic meatus of the external ear ends at the tympanic membrane and its mucosa contains sebaceous and ceruminous glands that produce an antimicrobial substance, cerumen.
- The tympanic cavity of the middle ear opens to the nasopharynx via the auditory (eustachian) tube.
- Within the tympanic cavity, an articulated series of three small bony ossicles (malleus, incus, and stapes) connects the tympanic membrane with the oval window in the wall of the internal ear.
- The internal ear consists of a membranous labyrinth containing endolymph; the membranous labyrinth is enclosed by the temporal bone's bony labyrinth which contains perilymph.
- The membranous labyrinth has a central vestibule with two subdivisions: the utricle connects to the three semicircular ducts and the saccule connects to the cochlear duct.
- The walls of the utricle and saccule each have a thickened area, the macula, which contains both sensory hair cells with synaptic connections to sensory nerves and supporting cells.
- A bundle of rigid stereocilia and one rigid kinocilium project apically from each hair cell and are surrounded by endolymph containing a gel-like matrix with mineralized crystals called otoliths.
- Head movements cause endolymph and the otolithic membrane to move, deforming the rigid apical structures of the hair cells, depolarizing them and producing nerve impulses.
- Each of the semicircular ducts, oriented 90 degrees from one another, has a terminal ampulla region with a thickened crista ampullaris containing hair cells that contact a gel-like cupola.
- Head movements displace endolymph and stereocilia of hair cells in the utricle, saccule, and semicircular ducts which together produce signals that contribute to the sense of equilibrium.
- The cochlear duct is the middle compartment (scala media) of the cochlea and runs between two other long compartments that contain perilymph: the scala vestibuli and the scala tympani.
- Along the base of the cochlear duct, the basilar membrane supports the spiral organ of Corti, which consists largely of hair cells connected to sensory fibers of cranial nerve VIII.
- The cochlear hair cells include three to five rows of outer hair cells with stereocilia embedded in a gel-like tectorial membrane and one row of more heavily innervated inner hair cells.
- Sound waves transmitted by the ossicles move the oval window and produce pressure waves in the cochlear perilymph which deflect the basilar membrane and organ of Corti, causing nerve impulses which the brain interprets as sounds.

The Eye & Ear: Special Sense Organs ASSESS YOUR KNOWLEDGE

1. Which of the following is the thickest component of the cornea?
   a. Corneal epithelium
   b. Stroma
   c. Descemet membrane
   d. Bowman membrane
   e. Corneal endothelium

2. Which description is accurate for lens fibers?
   a. Are terminally differentiated fibroblasts
   b. Consist of specialized type I collagen
   c. Derived from epithelial cells that produce proteins called crystallins
   d. Consist of type III collagen
   e. Have the same embryonic origin as the neural retina

3. Which structure is the most anterior extension of the eye's vascular layer?
   a. Ciliary body
   b. Cornea
   c. Lens
   d. Iris
   e. Zonule

4. Which cells transmit visual signals from the retina to the brain?
   a. Bipolar cells
   b. Amacrine cells
   c. Ganglion cells
   d. Horizontal cells
   e. Müller cells