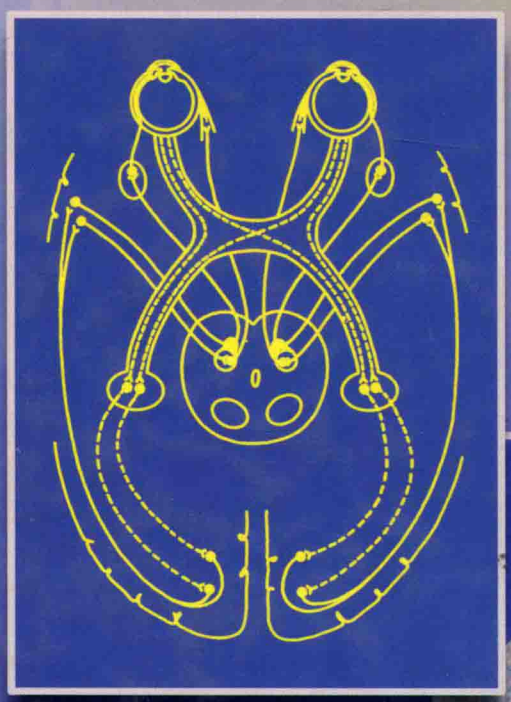
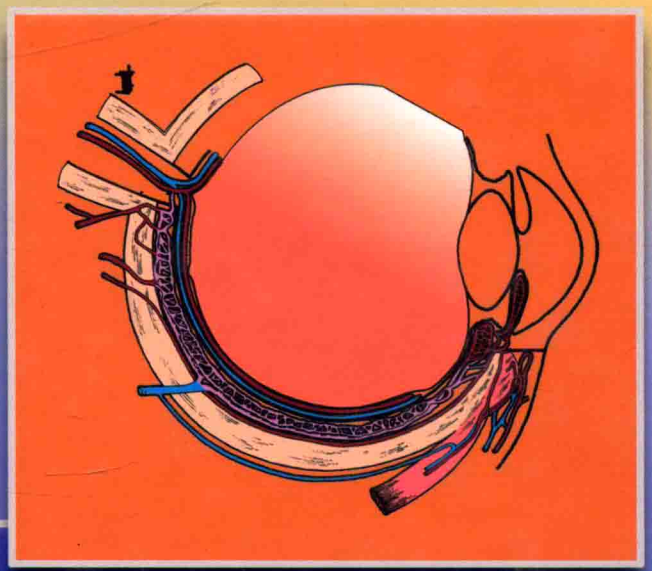
ELSEVIER
BUTTERWORTH
HEINEMANN

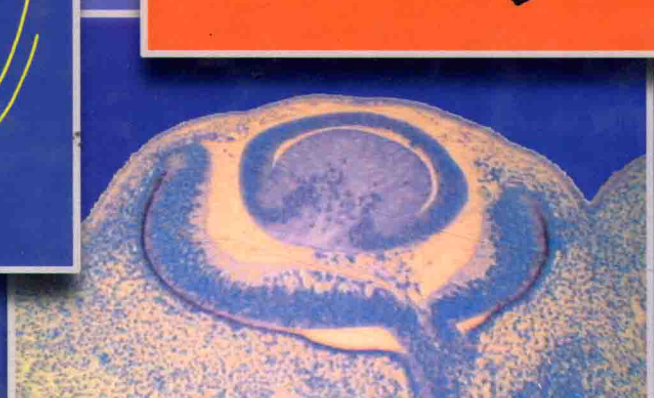
SECOND EDITION

Clinical Anatomy OF THE VISUAL SYSTEM

LEE ANN REMINGTON



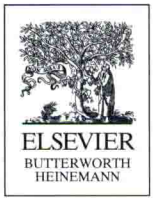




Clinical Anatomy OF THE *VISUAL SYSTEM*

LEE ANN REMINGTON, OD, MS
Professor of Optometry
Pacific University College of Optometry
Forest Grove, Oregon

SECOND EDITION



ELSEVIER
BUTTERWORTH
HEINEMANN

11830 Westline Industrial Drive
St. Louis, Missouri 63146

CLINICAL ANATOMY OF THE VISUAL SYSTEM 0-7506-7490-3

NOTICE

Optometry is an ever-changing field. Standard safety precautions must be followed, but as new research and clinical experience broaden our knowledge, changes in treatment and drug therapy may become necessary or appropriate. Readers are advised to check the most current product information provided by the manufacturer of each drug to be administered to verify the recommended dose, the method and duration of administration, and contraindications. It is the responsibility of the licensed prescriber, relying on experience and knowledge of the patient, to determine dosages and the best treatment for each individual patient. Neither the publisher nor the author assumes any liability for any injury and/or damage to persons or property arising from this publication.

The Publisher

Previous edition copyrighted 1998

International Standard Book Number 0-7506-7490-3

Publishing Director: Linda Duncan
Managing Editor: Christie M. Hart
Publishing Services Manager: Patricia Tannian
Project Manager: Sarah Wunderly
Senior Design Manager: Gail Morey Hudson

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Clinical Anatomy OF THE VISUAL SYSTEM

To
Dan, Tracy, and **Ryan,**
the loves of my life

Preface

Clinical Anatomy of the Visual System was written to provide the optometry and ophthalmology student, as well as the clinician, with a single text that describes the embryology, anatomy, histology, blood supply, and innervation of the globe and ocular adnexa. The visual and pupillary pathways are covered as well. The text is fully referenced, and information gathered from historical and current literature is well documented. An overview of the visual system as well as a short review of histology is provided in the introductory chapter. Chapters 2 through 5 include the anatomy and the detailed histology of the structures constituting the globe. Each of the three coats of the eye, cornea-sclera, uvea, and retina, is covered in a separate chapter. Included in each is an emphasis on similarities and differences between regions within each coat and notations about layers that are continuous between structures and regions. The crystalline lens is covered in Chapter 5 and the globe is completed in Chapter 6 with descriptions of the chambers of the eye and the material that occupies those spaces.

In my experience, students can more easily grasp the intricacies of ocular development after having a comprehensive understanding of the composition of the structures; therefore, ocular embryology is covered in Chapter 7. The tissue and structures associated with and surrounding the globe are described in the next three chapters. First is a review of the bones and important foramen of the entire skull and then the detail regarding the orbital bones and connective tissue. This is followed by a chapter detailing eyelid structure and histology, including the roles that the muscles and glands have in tear film secretion and drainage. The chapter on the extraocular muscles describes movements that result from contraction of the muscles with the eye in various positions of gaze; an explanation of the clinical assessment of extraocular muscle function based on the anatomy is included.

The branches of the internal and the external carotid arteries that supply the globe and adnexa are identified in Chapter 11. The cranial nerve supply to orbital structures, including both sensory and motor pathways, is clarified, with an emphasis on the clinical relevance and implications of interruptions along the pathways. Significant detail on the relationship between the structures of the visual pathway and neighboring structures and on the orientation of the fibers as they course through the cranium en route to the striate cortex is presented in Chapter 13. Examples are given of characteristic visual field defects associated with injury to various regions of the pathway. The final chapter presents the autonomic pathways to the smooth muscles of the orbit and to the lacrimal gland. The pupillary pathway is included in this chapter, as is a treatment of the more common pupillary abnormalities and the relation between the pathway and the clinical presentation. Some of the common pharmaceutical agents and their actions and pupillary effects are covered as well.

In the format used in the text, terms and names of structures are noted in bold print when they are first described or explained. The name for a structure that is more common in usage is presented first, followed by other terms by which that structure is also known. Current nomenclature tends to use the more descriptive name rather than proper nouns when identifying structures, but that is not always the case, especially when the proper name of an individual has been linked so closely historically (e.g., Schwalbe's line and Schlemm's canal).

Experienced clinicians know that the knowledge of structure provides a good foundation for recognizing and understanding clinical situations, conditions, diseases, and treatments. For this reason clinical comments are included throughout the book to emphasize common clinical problems, disease processes, or abnormalities that have a basis in anatomy.

Lee Ann Remington

Acknowledgments

I have had the pleasure of interacting with numerous bright, engaging students during the past 20 years while teaching ocular and visual anatomy courses at Pacific University College of Optometry. Their questions, corrections, suggestions, and enthusiasm motivate me to continually improve and update my understanding of the process we call vision.

I am also fortunate to work with an extraordinary group of colleagues, the faculty at Pacific, who produce an enjoyable environment conducive to academic growth. I am grateful to Dean Lee Carr for the constant level of support he provides, and to faculty at the college for their encouragement during this process.

I thank Daniel Howells, Nathan Owen, and Blake Simmons for their diligence. These optometry students spent hours during their summer break searching for pertinent literature references for me. Another student, Neil VanderHorst, spent many hours in the laboratory photographing microscope slides for the text. I appreciate all of their efforts and dedication. The original line drawings included from the first edition were done by Tracey Asmus, O.D.

I am grateful to my husband, Dan, for his patience, encouragement, and loving support during the months spent preparing this manuscript. I am indebted to my children, Tracy and Ryan, for enhancing the joy in my life.

Christie Hart, my editor at Elsevier, has guided me with kindness and tact throughout the entire process, and for that I am grateful. Sarah Wunderly, my project manager at Elsevier, competently combined the text and figures into a cohesive whole. I appreciated her thoughtful and gentle suggestions.

Contents

CHAPTER

1 Visual System

The visual system takes in information from the environment in the form of light and analyzes and interprets it. This process of sight and visual perception involves a complex system of structures, each of which is designed for a specific purpose. The organization of each structure enables it to perform its intended function.

The eye houses the elements that take in light rays and change them to a neural signal; it is protected by its location within the bone and connective tissue framework of the orbit. The eyelids cover and protect the anterior surface of the eye and contain glands that produce the lubricating tear film. Muscles, attached to the outer coat of the eye, control and direct the globe's movement, and the muscles of both eyes are coordinated to provide binocular vision. A network of blood vessels supplies nutrients, and a complex system of nerves provides sensory and motor innervation to the eye and surrounding tissues and structures. The neural signal that carries visual information passes through a complex and intricately designed pathway within the central nervous system, enabling an accurate view of the surrounding environment. This information, evaluated by a process called visual perception, influences myriad decisions and activities.

This book examines the macroscopic and microscopic anatomy of the components in this complex system and the structures that support it.

THE EYE

ANATOMIC FEATURES

The eye is a special sense organ made up of three coats, or tunics, as follows:

1. The outer fibrous layer of connective tissue forms the cornea and sclera.
2. The middle vascular layer is composed of the iris, ciliary body, and choroid.
3. The inner neural layer is the retina.

Within this globe are three spaces: the anterior chamber, posterior chamber, and vitreous chamber. The crystalline lens is located in the region of the posterior chamber (Figure 1-1).

The outer dense connective tissue of the eye provides protection for the structures within and maintains the shape of the globe, providing resistance to the pressure of the fluids inside. The **sclera** is the opaque white of the eye and is covered by the transparent conjunctiva. The transparent **cornea** allows light rays to enter the globe and, by refraction, helps bring these light rays into focus on the retina. The region in which the transition from cornea to sclera and conjunctiva occurs is the **limbus.**

The vascular layer of the eye is the **uvea,** which is made up of three structures, each having a separate function but all are interconnected. Some of the histologic layers are continuous throughout all three structures and are derived from the same embryonic germ cell layer. The **iris** is the most anterior structure, acting as a diaphragm to regulate the amount of light entering the pupil. The two iris muscles control the shape and diameter of the pupil and are supplied by the autonomic nervous system. Continuous with the iris at its root is the **ciliary body,** which produces the components of the aqueous humor and contains the muscle that controls the shape of the lens. The posterior part of the uvea, the **choroid,** is an anastomosing network of blood vessels with a dense capillary network; it surrounds the retina and supplies nutrients to the outer retinal layers.

The neural tissue of the retina, by complex biochemical processes, changes light energy into a signal that can be transmitted along a neural pathway. The signal passes through the retina, exits the eye through the **optic nerve,** and is transmitted to various parts of the brain for processing.

The interior of the eye is made up of three chambers. The **anterior chamber** is bounded in front by the cornea and posteriorly by the iris and anterior surface of the lens. The **posterior chamber** lies behind the iris and surrounds the equator of the lens, separating it from the ciliary body. The anterior and posterior chambers are continuous with one another through the pupil, and both contain aqueous humor that is produced by the ciliary body. The **aqueous humor** provides nourishment for the surrounding structures, particularly the cornea and lens. The **vitreous chamber,** which is the largest space, lies adjacent to the inner retinal layer and is bounded in front by the lens. This chamber contains a gel-like substance, the **vitreous humor.**

The **crystalline lens** is located in the area of the posterior chamber and provides additional refractive

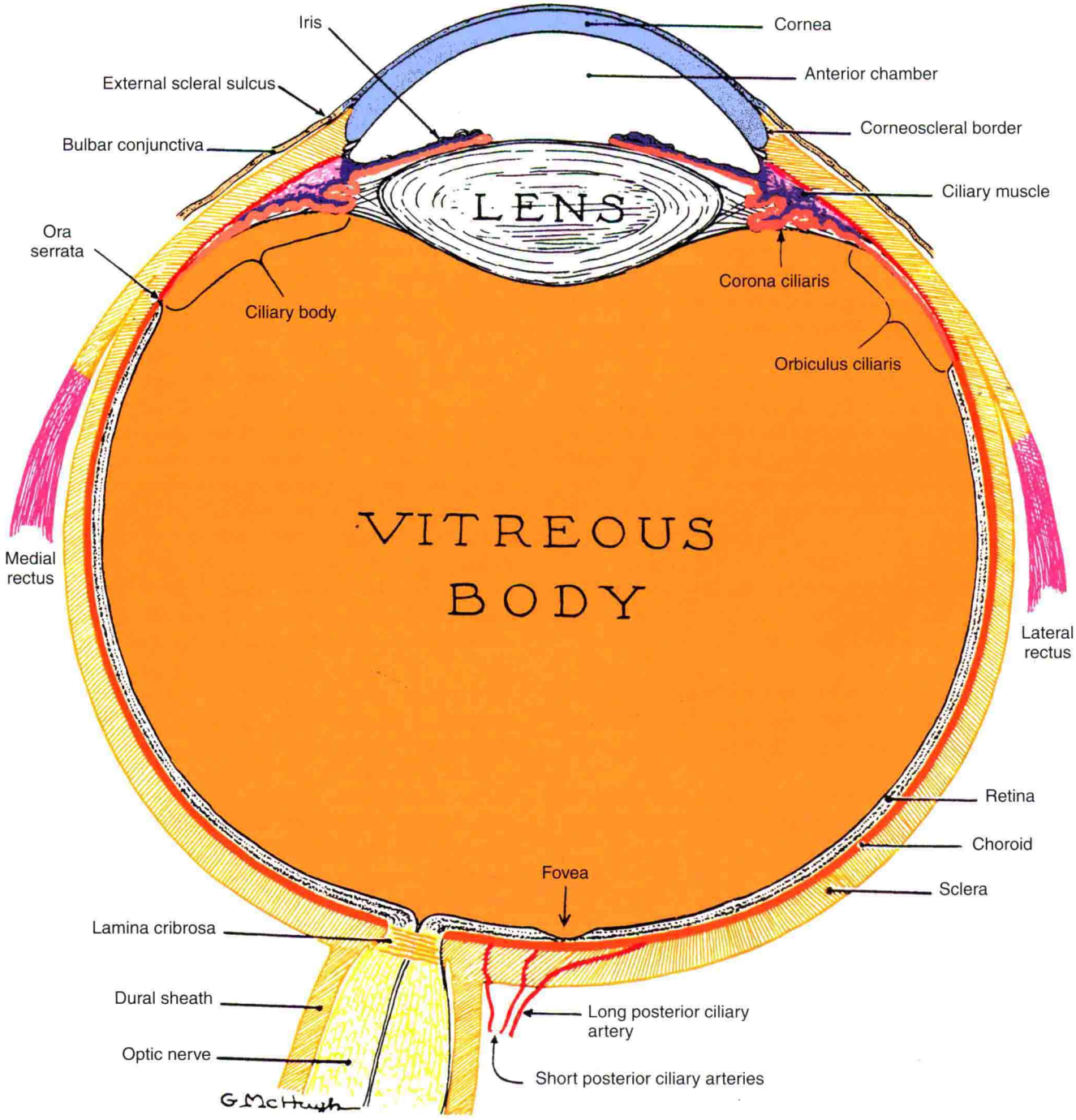


FIGURE 1-1
The visual system. (From Kronfeld PC: *The human eye,* Rochester, NY, 1943, Bausch & Lomb Press.)

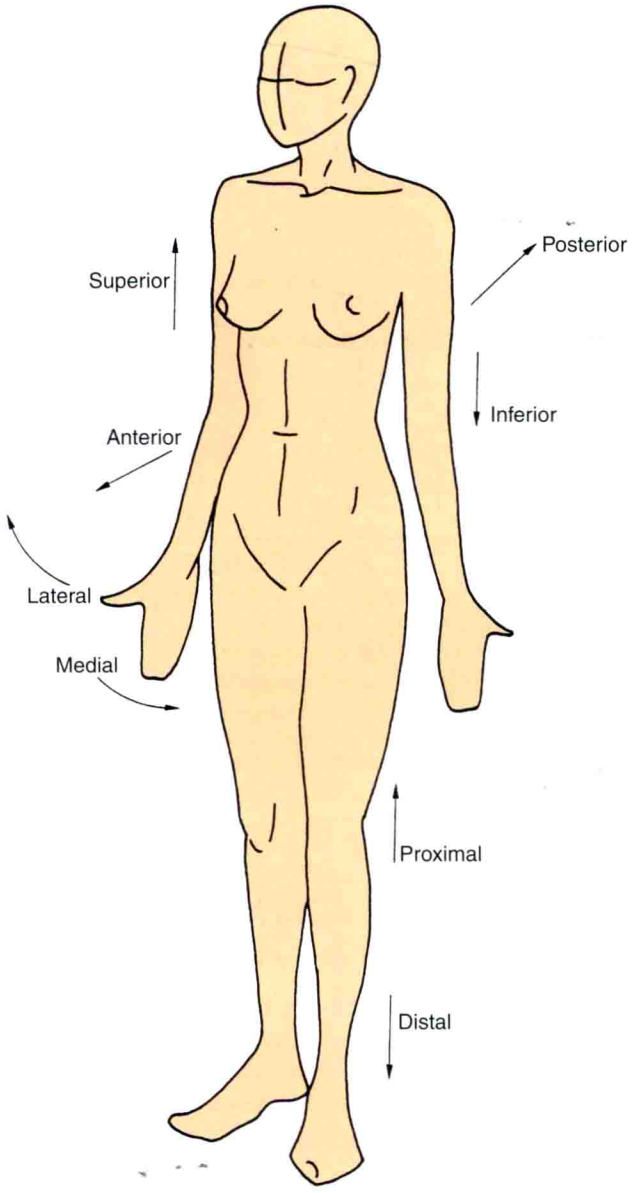


FIGURE 1-2
Anatomic directions. (From Palastanga N, Field D, Soames R: *Anatomy and human movement,* Oxford, England, 1989, Butterworth-Heinemann.)

power for accurately focusing images onto the retina. The lens must change shape to view an object that is close to the eye, through the mechanism of **accommodation.**

ANATOMIC DIRECTIONS AND PLANES

Anatomy is an exacting science, and specific terminology is basic to its discussion. The following anatomic directions should be familiar (Figure 1-2):

- Anterior, or ventral: toward the front
- Posterior, or dorsal: toward the back
- Superior, or cranial: toward the head
- Inferior, or caudal: away from the head
- Medial: toward the midline
- Lateral: away from the midline
- Proximal: near the point of origin
- Distal: away from the point of origin

The following planes are used in describing anatomic structures (Figure 1-3):

- Sagittal: vertical plane running from anterior to posterior locations, dividing the structure into right and left sides.
- Midsagittal: sagittal plane through the midline, dividing the structure into right and left halves.
- Coronal or frontal: vertical plane running from side to side, dividing the structure into anterior and posterior parts.
- Transverse: horizontal plane dividing the structure into superior and inferior parts.

Because the globe is a spheric structure, references to locations can sometimes be confusing. In references to *anterior* and *posterior* locations of the globe, the anterior pole (i.e., center of the cornea) is the reference point. For example, the pupil is anterior to the ciliary body (see Figure 1-1). When layers or structures are referred to as *inner* or *outer,* the reference is to the entire globe unless specified otherwise. The point of reference is the center of the globe, which would lie within the vitreous. For example, the retina is inner to the sclera (see Figure 1-1). In addition, the term *sclerad* is used to mean "toward the sclera," and *vitread* is used to mean "toward the vitreous."

REFRACTIVE CONDITIONS

If the refractive power of the optical components of the eye, primarily the cornea and lens, correlate with the distances between the cornea, lens, and retina so that incoming parallel light rays come into focus on the retina, a clear image will be seen. This condition is called **emmetropia** (Figure 1-4, *A*). No correction is necessary for clear distance vision. In **hyperopia** (farsightedness) the distance from the cornea to the retina is too short for the refractive power of the cornea and lens, thereby causing images that would come into focus *behind* the retina (Figure 1-4, *B*). Hyperopia can be corrected by placing a convex lens in front of the eye to increase the convergence of the incoming light rays. In **myopia** (nearsightedness), because the lens and cornea are too strong or, more likely, the eyeball is too long, parallel light rays are brought into focus in *front* of the retina (Figure 1-4, *C*). Myopia can be corrected by placing a concave lens in front of the eye, causing the incoming light rays to diverge.

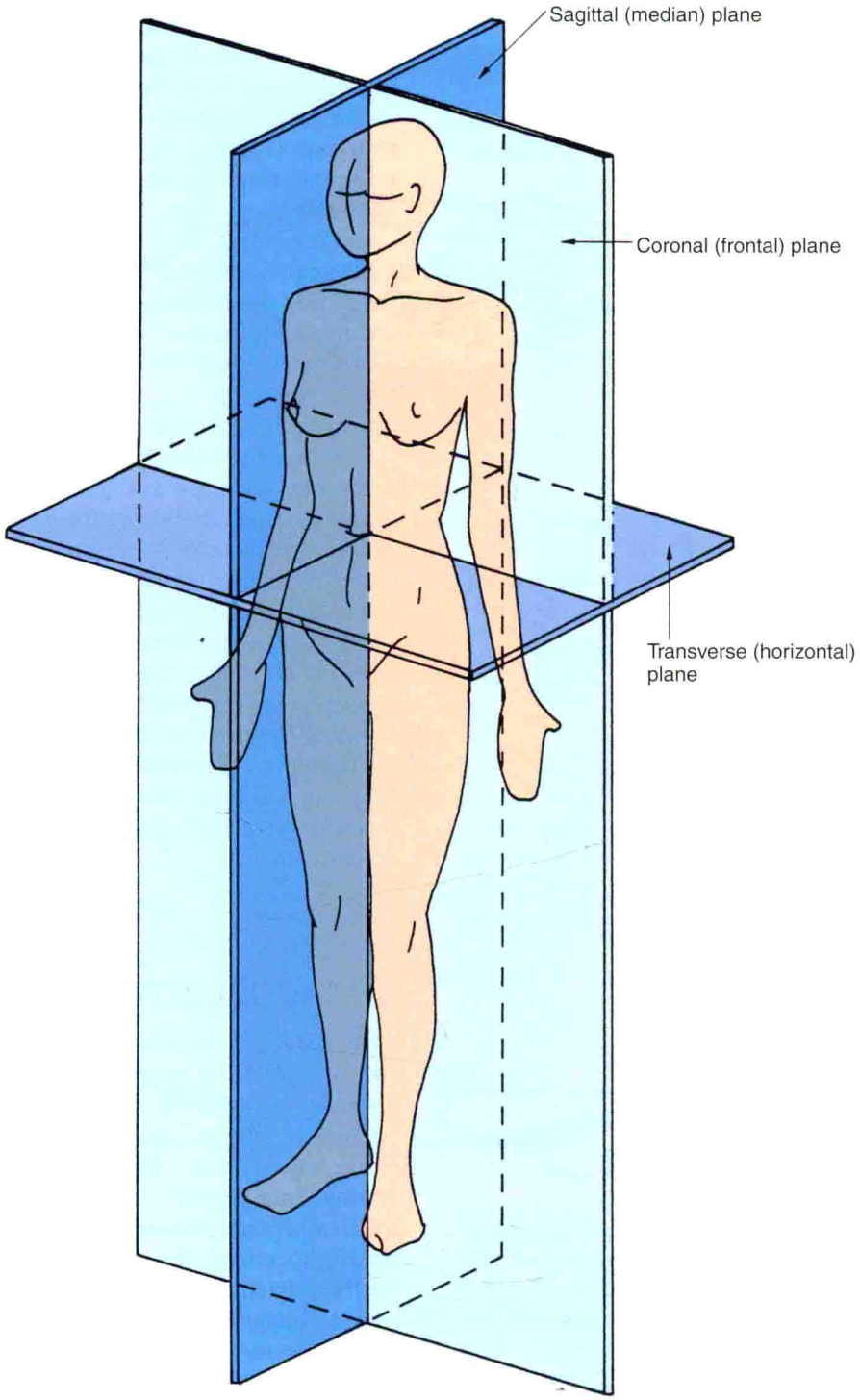


FIGURE 1-3
Anatomic planes. (From Palastanga N, Field D, Soames R: *Anatomy and human movement*, Oxford, England, 1989, Butterworth-Heinemann.)

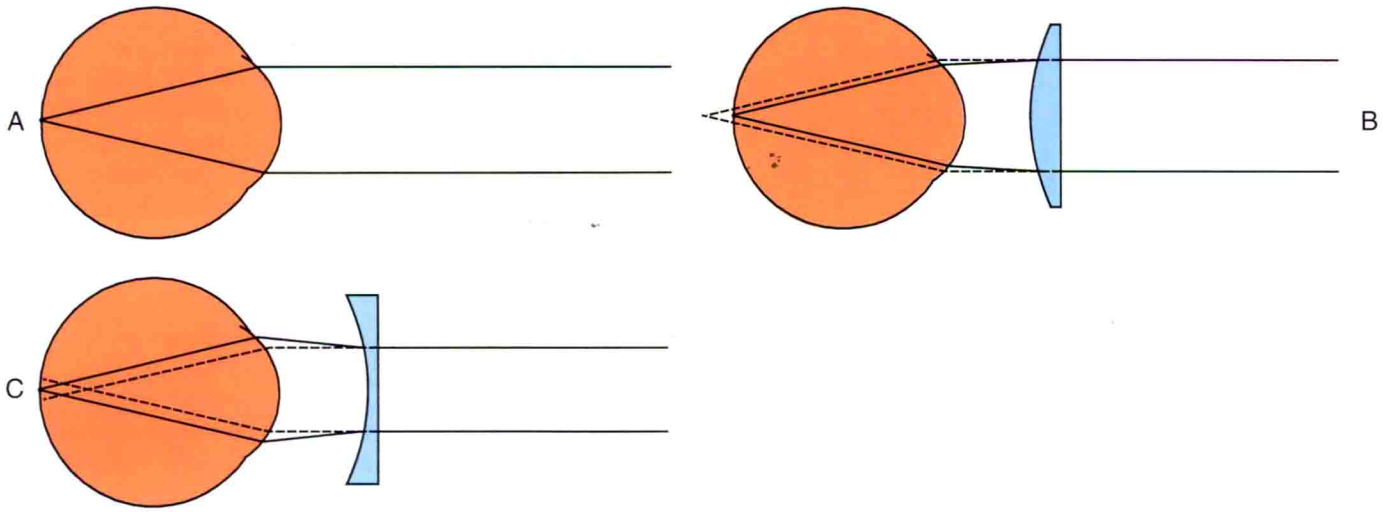


FIGURE 1-4
Refractive conditions. **A,** Emmetropia, in which parallel light comes to a focus on the retina. **B,** Hyperopia, in which parallel light comes to a focus behind the retina *(dotted lines).* A convex lens is used to correct the condition and bring the light rays into focus on the retina. **C,** Myopia, in which parallel light comes to a focus in front of retina *(dotted lines).* A concave lens is used to correct the condition and bring the light rays into focus on the retina. (Courtesy Dr. Karl Citek, Pacific University, Forest Grove, Ore.)

OPHTHALMIC INSTRUMENTATION

Various instruments are used to assess the health and function of elements of the visual pathway and the supporting structures. This section briefly describes some of these instruments and the structures examined.

The curvature of the cornea is one of the factors that determine the corneal refractive power. A *keratometer* measures the curvature of the central 3 to 4 mm of the anterior corneal surface and provides information about the power and the difference in curvature between the principle meridians at that location. The smoothness of the corneal surface can also be assessed by the pattern reflected from the cornea during the measuring process. The *automated corneal topographer* maps the corneal surface and gives an indication of curvatures at selected points. This instrument is an important adjunct in the fitting of contact lenses in difficult cases.

The optometric physician can determine the optical power of the eye with a set of lenses and a *retinoscope.* This instrument is beneficial also for assessing the accommodative function of the lens.

The inside of the eye, called the **fundus,** is examined using an *ophthalmoscope,* which illuminates the interior with a bright light. The retina, optic nerve head, and blood vessels can be assessed and information about ocular and systemic health obtained. This is the only place in the body in which blood vessels can be viewed directly and noninvasively. Various systemic diseases, such as diabetes, hypertension, and arteriosclerosis, can alter ocular vessels. To obtain a more complete view of the inside of the eye, topical drugs are administered to influence the iris muscles, causing the pupil to become enlarged, or mydriatic.

The outside of the globe and the eyelids can be assessed with a *biomicroscope.* This combination of an illumination system and a binocular microscope allows stereoscopic views of various parts of the eye. Particularly beneficial is the view of the transparent structures, such as the cornea and lens. A number of auxiliary instruments can be used with the biomicroscope to measure intraocular pressure and to view the interior of the eye.

Technologic advances have produced instrumentation that can provide three-dimensional mapping of retinal and optic nerve head surfaces and measure the thickness of specific retinal layers.

The visual field is the area that a person sees when looking straight ahead, including those areas seen "out of the corner of the eye." A *perimeter* is used to test the extent, sensitivity, and completeness of this visual field. Computerized perimeters provide extremely detailed maps of the visual field, as well as statistical information

on the reliability of the test and the probabilities of any defects.

BASIC HISTOLOGIC FEATURES

Because many of the anatomic structures are discussed in this book at the histologic level, this section briefly reviews basic human histology. Other details of tissues are addressed in the pertinent chapters.

All body structures are made up of one or more of the four basic tissues: epithelial, connective, muscle, and nervous tissue. A tissue is defined as a collection of similar cells that are specialized to perform a common function.

EPITHELIAL TISSUE

Epithelial tissue often takes the form of sheets of epithelial cells that either cover the external surface of a structure or that line a cavity. Epithelial cells lie on a basement membrane that attaches them to underlying connective tissue. The basement membrane can be divided into two parts: the **basal lamina,** secreted by the epithelial cell, and the **reticular lamina,** a product of the underlying connective tissue layer.[1] The free surface of the epithelial cell is the *apical* surface, whereas the surface that faces underlying tissue or rests on the basement membrane is the *basal* surface.

Epithelial cells are classified according to shape. Squamous cells are flat and platelike, cuboidal cells are of equal height and width, and columnar cells are higher than wide. Epithelium consisting of a single layer of cells is referred to as *simple:* simple squamous, simple cuboidal, or simple columnar. *Endothelium* is the special name given to the simple squamous layer that lines certain cavities. Epithelium consisting of several layers is referred to as *stratified* and is described by the shape of the cells in the surface layer. Only the basal or deepest layer of cells is in contact with the basement membrane, and this layer usually consists of columnar cells.

Keratinized, stratified squamous epithelium has a surface layer of squamous cells with cytoplasm that has been transformed into a substance called *keratin,* a tough protective material relatively resistant to mechanical injury, bacterial invasion, and water loss. These keratinized surface cells constantly are sloughed off and are replaced from the layers below, where cell division takes place.

Glandular Epithelium

Many epithelial cells are adapted for secretion and, when gathered into groups, are referred to as *glands.* Glands can be classified according to the manner of secretion—*exocrine* glands secrete into a duct, whereas *endocrine* glands secrete directly into the bloodstream—or to the mechanism of secretion—*holocrine* glands secrete complete cells laden with the secretory material; *apocrine* glands secrete part of the cell cytoplasm in the secretion; and the secretion of *merocrine* glands is a product of the cell without loss of any cellular components. Glands can also be named according to the nature of their secretion: *mucous, serous,* or *sebaceous.*

Intercellular Junctions

Various intercellular junctions join epithelial cells to one another and to adjacent tissue. In a tight (occluding) junction, the outer leaflet of the cell membrane of one cell comes into direct contact with its neighbor. These points of apposition are actually points along ridgelike elevations that fuse with complementary ridges on the surface of the neighboring cell.[2]

A tight junction that forms a zone or belt around the entire cell and joins it with each of the adjacent cells is called a **zonula occludens** (Figure 1-5). In these zones, row on row of intertwining ridges effectively occlude the intercellular space. For a substance to pass through a sheet of epithelium with cells joined by zonula occludens, the substance must pass *through* the cell itself; it cannot pass *between* cells through the intercellular space. In some instances, ridges are fewer and discontinuous, resulting in a "leaky epithelium."[2]

A **zonula adherens,** an intermediate junction, is a similar adhesion zone. However, the adjacent plasma membranes are separated by a narrow intercellular space that contains a specific glycoprotein, cell adhesion molecule, material that contributes to cell stability and adhesion.[3] Adjacent to the adhering junction are fine microfilaments that extend from the membrane into the cytoplasm.[2] These produce relatively firm adhesion. A **terminal bar** consists of a zonula occludens and a zonula adherens side by side, with the tight junction lying nearest the cell apex.[1,2]

Round, buttonlike intercellular junctions have been called **macula occludens** or **macula adherens,** depending on the type of adhesion.

A **desmosome** (macula adherens) is a strong, spotlike attachment between cells. A dense disc or plaque is present within the cytoplasm adjacent to the plasma membrane at the site of the adherence, and hairpin loops of cytoplasmic filaments called tonofilaments extend from the disc into the cytoplasm, contributing to cell stability. Other filaments, transmembrane linkers, extend from the plaque across the intercellular space, holding the cell membranes together and forming a strong bond.[3] The intercellular space contains an acid-rich mucoprotein that acts as a

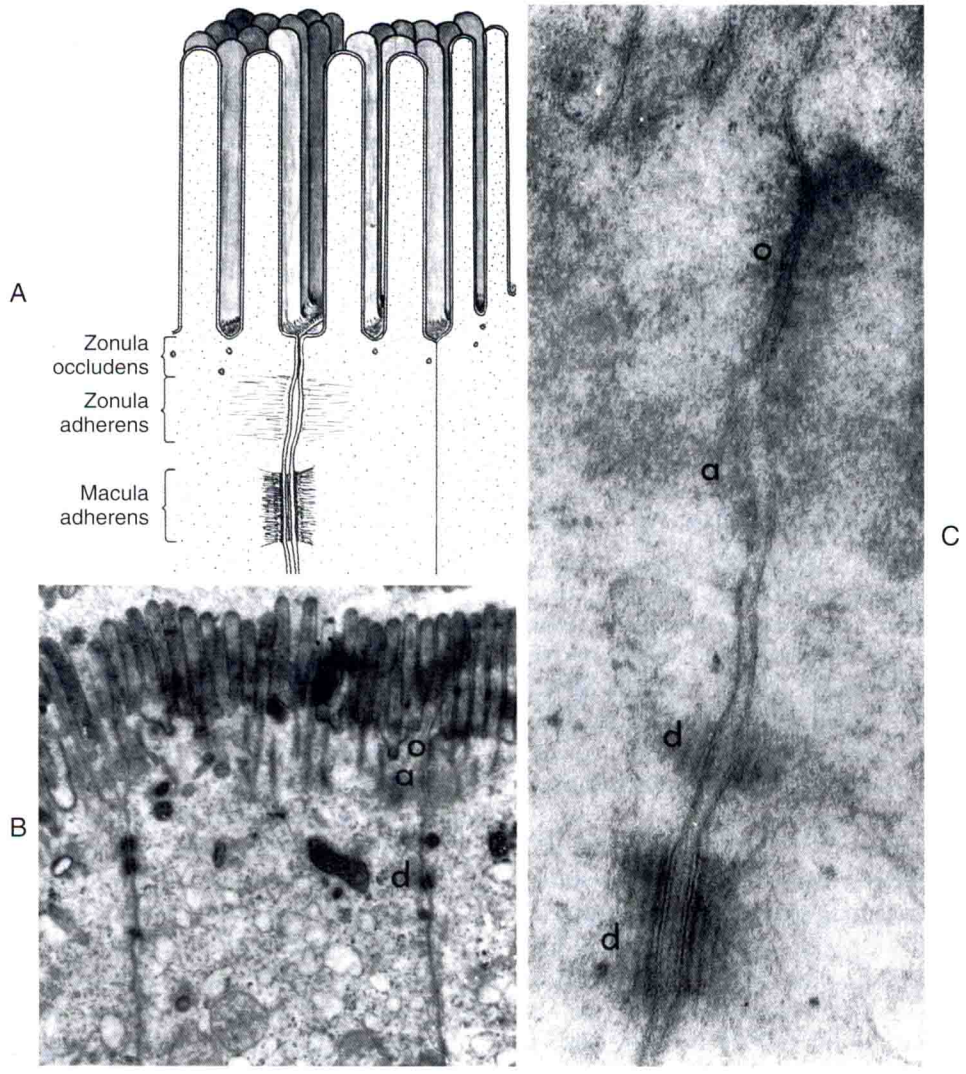


FIGURE 1-5
Junctional complex. **A,** Appearance on electron microscopy of the apical cell interface between two epithelial cells with microvilli on the apical surfaces. **B,** Electron micrograph shows the apical portion of one such cell. (×18,000.) **C,** Electron micrograph shows features of the junctional complex at high magnification. (×105,000.) *o,* Zonula occludens; *a,* zonula adherens; *d,* macula adherens, or desmosome. (From Leeson CR, Leeson ST: *Histology,* Philadelphia, 1976, Saunders.)

strong adhesive.[2] A **hemidesmosome** attaches an epithelial cell to its basement membrane and the underlying connective tissue. Bundles of filaments pass through the cell membrane and the adhesive joining the intracellular plaque to the underlying connective tissue.

A **gap junction,** or communicating junction, is macular in shape. The cells are separated by a thin, intercellular space through which small channels called *connexins* pass, joining the cytoplasm of the two cells.[3] These junctions allow for intercellular communication and exchange of ions from one cell to the next.[1,2]

CONNECTIVE TISSUE

Connective tissue provides structure and support and is a "space filler" for areas not occupied by other tissue. Connective tissue consists of cells, fibers, and ground substance. Ground substance and fibers collectively are called matrix. Connective tissue can be classified as *loose*

or *dense*. Loose connective tissue has relatively fewer cells and fibers per area than dense connective tissue, in which the cells and fibers are tightly packed. Dense connective tissue can be characterized as *regular* or *irregular* on the basis of fiber arrangement.

Among the cells that may be found in connective tissue are fibroblasts (flattened cells that produce and maintain the fibers and ground substance), macrophages (phagocytic cells), mast cells (which contain heparin and histamine), and fat cells. Connective tissue composed primarily of fat cells is called adipose tissue.

The fibers found in connective tissue include flexible collagen fibers with high tensile strength, delicate reticular fibers, and elastic fibers, which can undergo extensive stretching. Collagen fibers are a major component of much of the eye's connective tissue. These fibers are composed of protein macromolecules of tropocollagen that have a coiled helix of three polypeptide chains. The individual polypeptide chains can differ in their amino acid sequences, and the tropocollagen has a banded pattern because of the sequence differences.[4] Collagen is separated into various types on the basis of such differences, and several types are components of ocular connective tissue structures.

The amorphous ground substance, in which the cells and fibers are embedded, consists of water bound to glycosaminoglycans and long-chain carbohydrates.

MUSCLE TISSUE

Muscle tissue is contractile tissue and can be classified as *striated* or *smooth*, *voluntary* or *involuntary*. Striated muscle has a regular pattern of light and dark bands and is subdivided into skeletal and cardiac muscle. Skeletal muscle is under voluntary control, whereas cardiac muscle is controlled involuntarily. The structure of skeletal muscle and the mechanism of its contraction are discussed in Chapter 10.

The smooth muscle fiber is an elongated, slender cell with a single centrally located nucleus. The tissue is under the involuntary control of the autonomic nervous system.

NERVE TISSUE

Nerve tissue contains two types of cells: **neurons,** which are specialized cells that react to a stimulus and conduct a nerve impulse, and **neuroglia,** which are cells that provide structure and metabolic support. The neuron cell body is the perikaryon, which has several cytoplasmic projections. The projections that conduct impulses *to* the cell body are dendrites (usually several), and the (usually single) projection that conducts impulses *away from* the cell body is an axon. These nerve fibers are either myelinated (enclosed in a lipoprotein material called myelin) or unmyelinated; myelinization improves impulse conduction speed.[5] Both myelinated and unmyelinated fibers are surrounded by Schwann cell cytoplasm; the Schwann cell produces the myelin.

A nerve impulse passes between nerves at a specialized junction, the synapse. As the action potential reaches the presynaptic membrane of an axon, a neurotransmitter is released into the synaptic gap, triggering an excitatory or an inhibitory response in the postsynaptic membrane.

Neuroglial cells outnumber neurons by a ratio of 10 to 50:1, depending on location.[5] Neuroglial cells include astrocytes, oligodendrocytes, and microglia. **Astrocytes** provide a framework that gives structural support and contributes to the nutrition of neurons. **Oligodendrocytes** produce myelin in the central nervous system, where there are no Schwann cells. **Microglia** possess phagocytic properties and increase in number in areas of damage or disease.[5]

REFERENCES

1. Krause WJ, Cutts JH: Epithelium. In Krause WJ, Cutts JH, editors: *Concise text of histology,* Baltimore, 1981, Williams & Wilkins, p 27.
2. Copenhaver WM, Kelly DE, Wood RL: Epithelium. In Copenhaver WM, Kelly DE, Wood RL, editors: *Bailey's textbook of histology,* ed 17, Baltimore, 1978, Williams & Wilkins, p 103.
3. Fawcett DW, Jensh RP: *Bloom & Fawcett concise histology,* 1997, Chapman & Hall, p 19.
4. Copenhaver WM, Kelly DE, Wood RL: The connective tissues. In Copenhaver WM, Kelly DE, Wood RL, editors: *Bailey's textbook of histology,* ed 17, Baltimore, 1978, Williams & Wilkins, p 142.
5. Krause WJ, Cutts JH: Nervous tissue. In Krause WJ, Cutts JH, editors: *Concise text of histology,* Baltimore, 1981, Williams & Wilkins, p 137.

CHAPTER

2 Cornea and Sclera

The outer connective tissue coat of the eye has the appearance of two joined spheres. The smaller, anterior transparent sphere is the cornea and has a radius of curvature of approximately 8 mm. The larger, posterior opaque sphere is the sclera, which has a radius of approximately 12 mm (Figure 2-1, *A*). The globe is not symmetric; its approximate diameters are 24 mm anteroposterior, 23 mm vertical, and 23.5 mm horizontal.[1]

CORNEA

CORNEAL DIMENSIONS

The transparent cornea appears, from the front, to be oval, as the sclera encroaches on the superior and inferior aspects. The anterior horizontal diameter is 12 mm, and the anterior vertical diameter is 11 mm.[1,2] If viewed from behind, the cornea appears circular, with horizontal and vertical diameters of 11.7 mm (Figure 2-1, *B*).[1,3]

In profile, the cornea has an elliptic rather than a spheric shape, the curvature being steeper in the center and flatter near the periphery. The radius of curvature of the central cornea at the anterior surface is 7.8 mm and at the posterior surface is 6.5 mm.[1,4] The central corneal thickness is 0.53 mm, whereas the corneal periphery is 0.71 mm thick (Figure 2-1, *C*).[1,4-6] (All values given are approximations.)

CLINICAL COMMENT: ASTIGMATISM

Astigmatism *is a condition in which light rays coming from a point source are not imaged as a point. This results from the unequal refraction of light by different meridians of the refracting elements. Because it is usually elliptic in profile, the cornea contributes to astigmatism in the eye as it refracts light and helps to focus the rays onto the retina. The curvature of the surface of the cornea (central 3 to 4 mm) can be determined by keratometric measurement to give a clinical assessment of the corneal contribution to astigmatism.*

Regular astigmatism *occurs when the longest radius of curvature and shortest radius of curvature lie 90 degrees apart. The usual presentation occurs when the radius of curvature of the vertical meridian differs from that of the horizontal meridian. The most common situation, called* ***with-the-rule astigmatism,*** *occurs when the steepest curvature lies in the vertical meridian. Thus, the vertical meridian has the shortest radius of curvature.* ***Against-the-rule*** *astigmatism is not as common and occurs when the horizontal meridian is the steepest; the greatest refractive power is found in the horizontal meridian. If the meridians that contain the greatest differences are not along the 180- and 90-degree axes (±30 degrees) but lie along the 45- and 135-degree axes (±15 degrees), the astigmatism is called* ***oblique. Irregular astigmatism*** *is an uncommon finding in which the meridians corresponding to the greatest differences are not 90 degrees apart.*

In addition to the cornea, the lens is a refractive element that focuses light rays and might contribute to astigmatism. In fact, the tendency of with-the-rule astigmatism to convert to against-the-rule astigmatism with aging is attributable primarily to the lens, which continues to grow throughout life.

CORNEAL HISTOLOGIC FEATURES

The **cornea** is the principal refracting component of the eye. Its transparency and avascularity provide optimal light transmittance. The anterior surface of the cornea is covered by the tear film, and the posterior surface borders the aqueous-filled anterior chamber. At its periphery the cornea is continuous with the conjunctiva and the sclera. From anterior to posterior, the five layers that compose the cornea are epithelium, Bowman's layer, stroma, Descemet's membrane, and endothelium (Figure 2-2).

Epithelium

The outermost layer of stratified corneal **epithelium** is five to seven cells thick and measures approximately 50 µm.[1,7] The epithelium thickens in the periphery and is continuous with the conjunctival epithelium at the limbus.

The surface layer of corneal epithelium is two cells thick and displays a very smooth anterior surface. It consists of *nonkeratinized* squamous cells, each of which contains a flattened nucleus and fewer cellular organelles than deeper cells. The plasma membrane of the surface epithelial cells is believed to secrete a glycocalyx component that adjoins the mucin layer of the tear film.[8-10] Many projections located on the apical surface of the outermost cells increase the surface area, thus enhancing the stability of the tear film. The