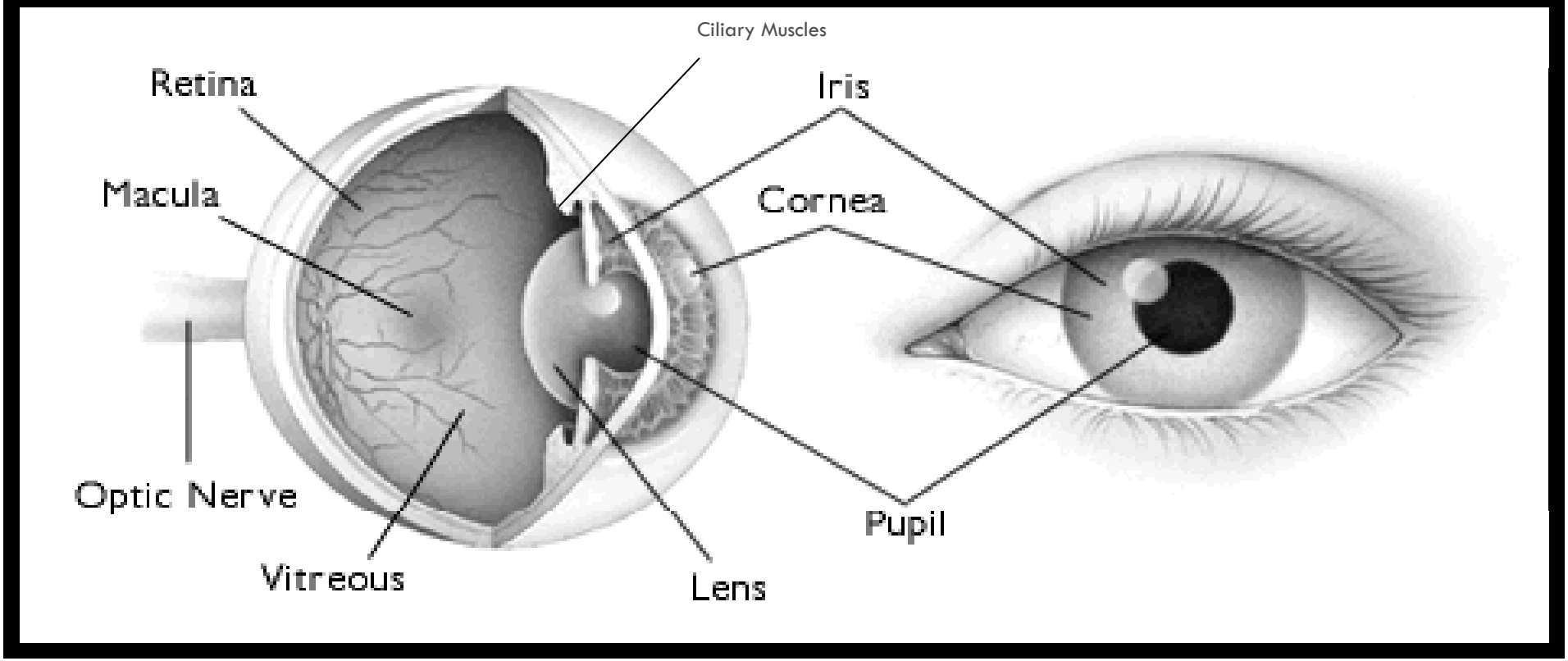
THE SPECIAL SENSES PART 1 VISION

D.HAMMOUDI.MD

The Eye and Vision



The Eye and Vision

- **70% of all sensory receptors are in the eye**
- Nearly half of the cerebral cortex is involved in processing visual information!
- Most of the eye is protected by a cushion of fat and the bony orbit

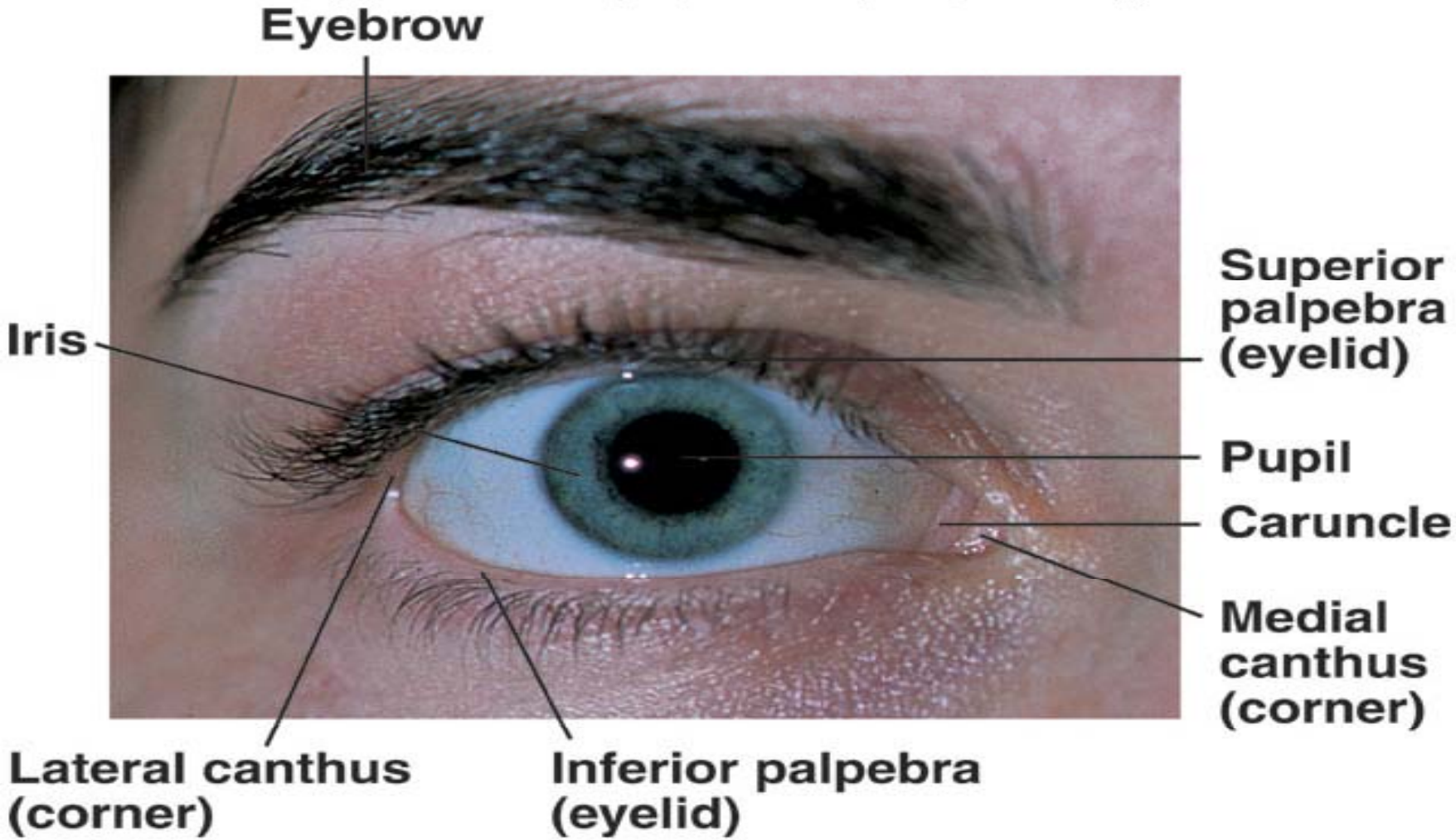
Amazing Eye

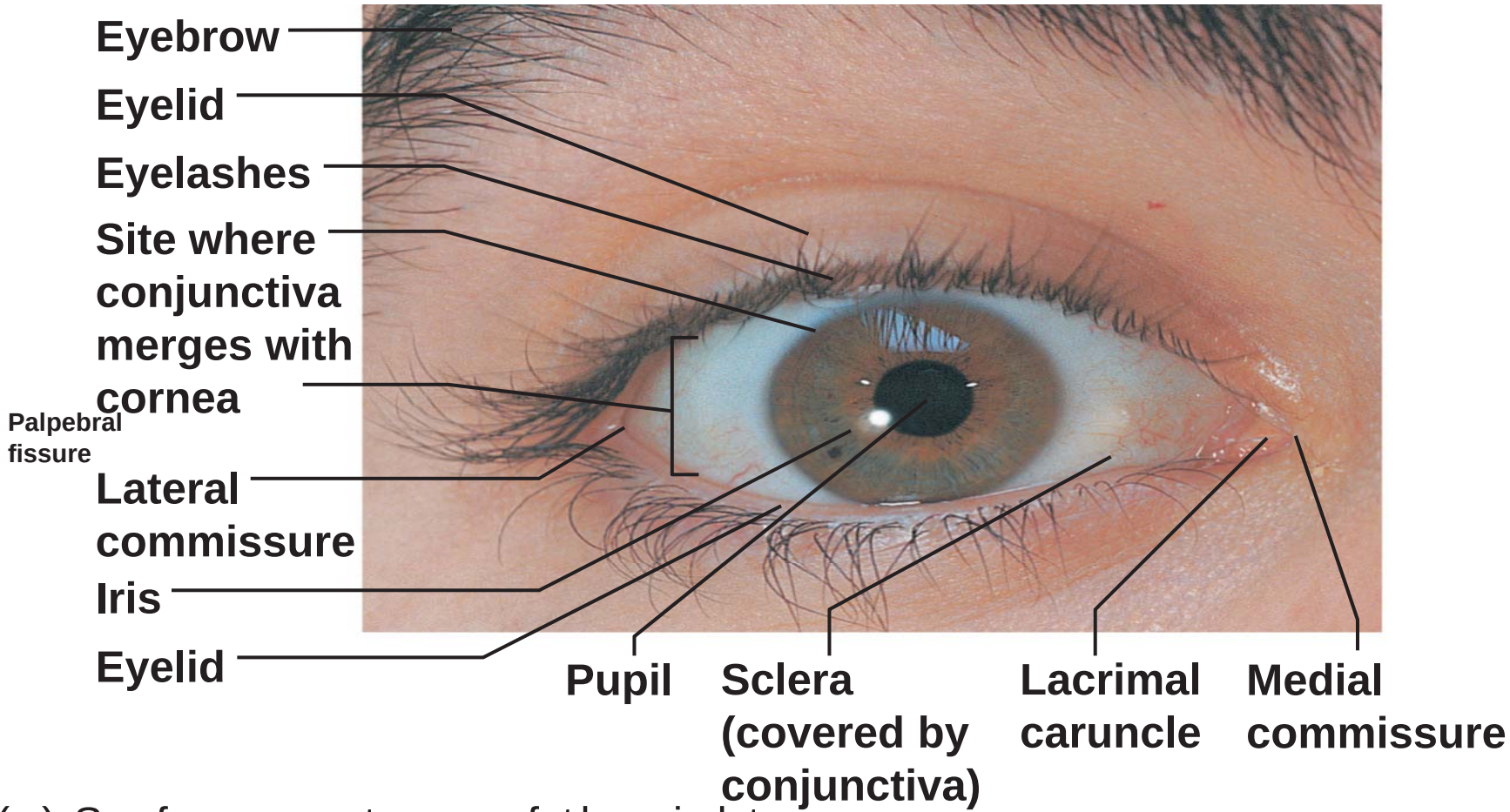
- One of first organs to develop.
- 100 million Receptors — 4 million
  - 200,000 /mm^2 — 2,500 /mm^2
  - Sensitive to single photon!
- Candle from 12 miles

Numbers in red are for a digital camera
Macula/fovea is super sensitive part only sees about 15 degrees

Accessory Structures of the Eye

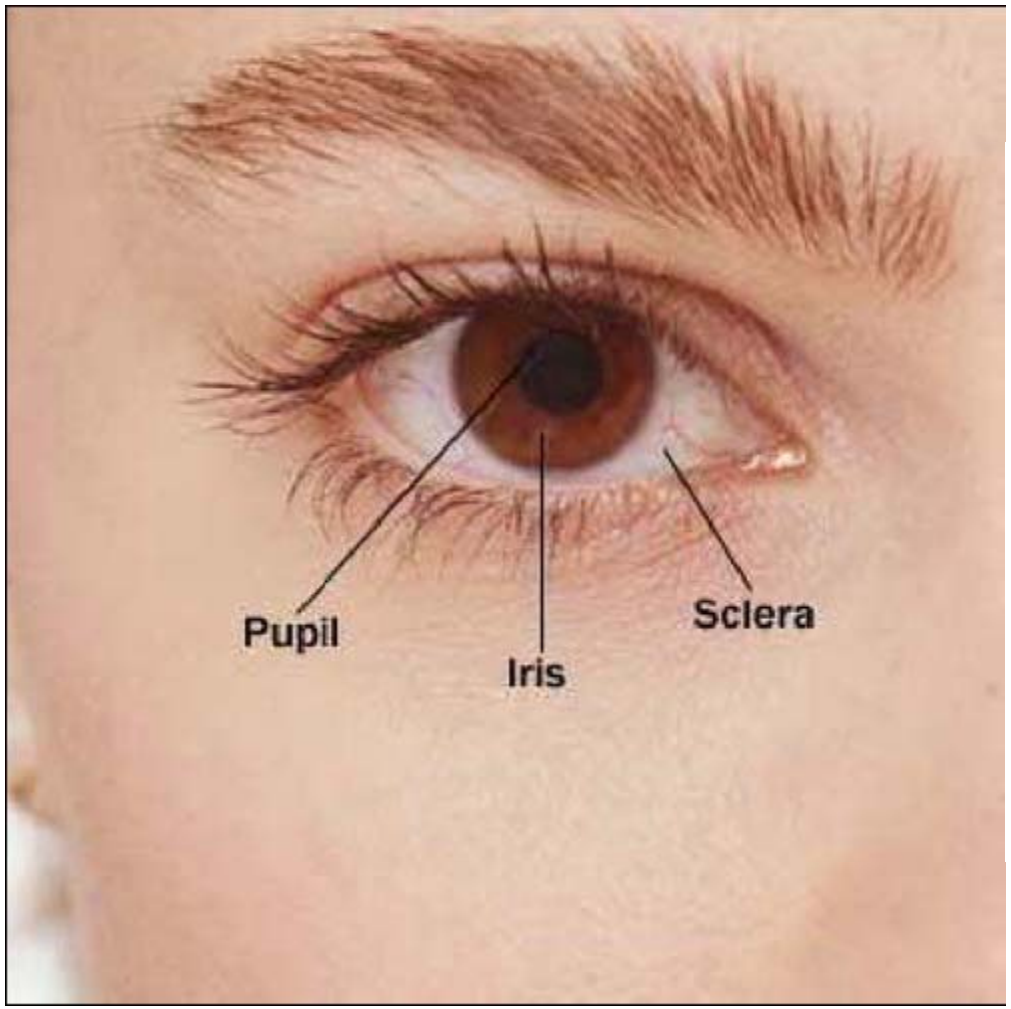
- Protect the eye and aid eye function
  - Eyebrows
  - Eyelids (palpebrae)
  - Conjunctiva
  - Lacrimal apparatus
  - Extrinsic eye muscles





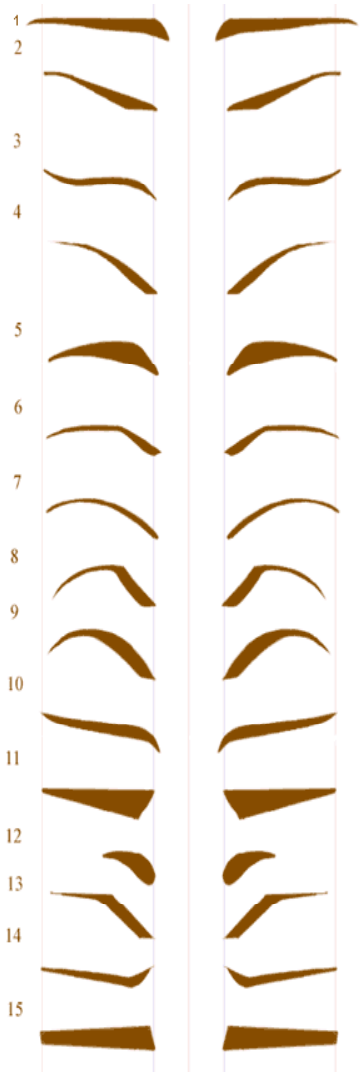
(a) Surface anatomy of the right eye

Figure 15.1a


Pupil
Iris
Sclera

Eyebrows

- Overlie the supraorbital margins
- Function in
  - Shading the eye
  - Preventing perspiration from reaching the eye



Eyelids

- Protect the eye anteriorly[light, injury, desiccation]
- Anterior/posterior lamella
- Extremely thin skin (upper > lower)
- Skin
  - Little subcutaneous fat
  - Adherent over the tarsus (levator aponeurosis)

- **Palpebral fissure**—separates eyelids
- **Lacrimal caruncle**—elevation at medial commissure; contains oil and sweat glands
- **Tarsal plates**—internal supporting connective tissue sheet
- **Levator palpebrae superioris**—gives the upper eyelid mobility

Eyelids

- **Eyelashes**
  - Nerve endings of follicles initiate reflex blinking
- **Lubricating glands associated with the eyelids**
  - **Tarsal (Meibomian) glands**
  - **Sebaceous glands associated with follicles**
  - **Ciliary glands between the hair follicles**

Anatomy

- Horizontal length – 30 mm
- Palpebral fissure – 10 mm
- Margin reflex distance
  - Number of millimeters from the corneal light reflex to the lid margin
  - Upper lid – 4 to 5 mm (rests slightly below limbus)
  - Lower lid – 5 mm (rests at the lower limbus
  - Reflex to limbus – 2.5 mm

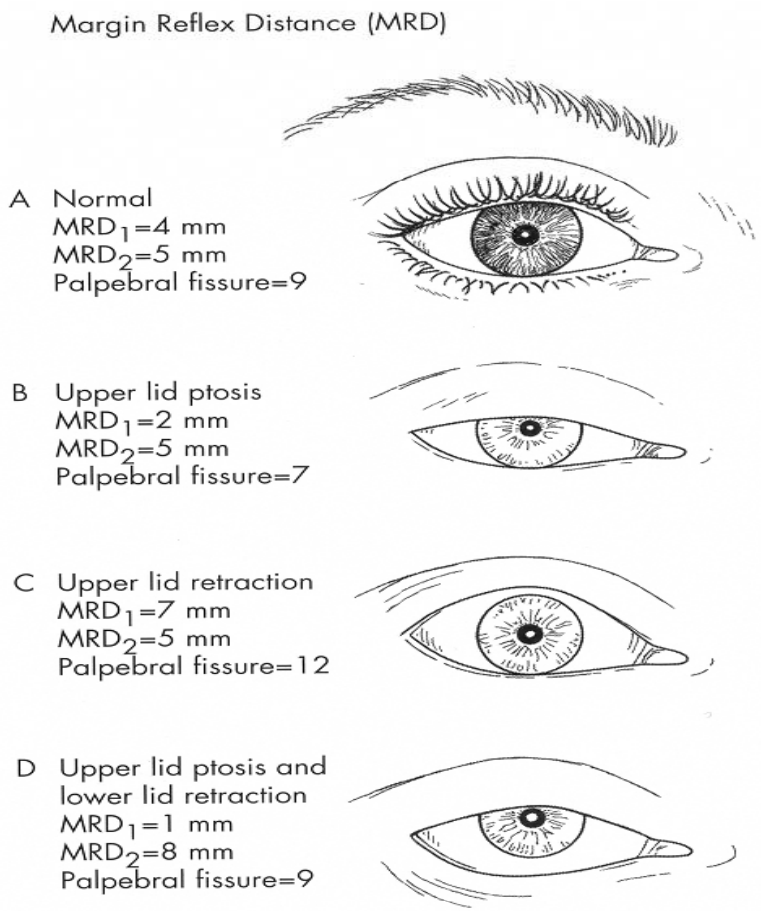
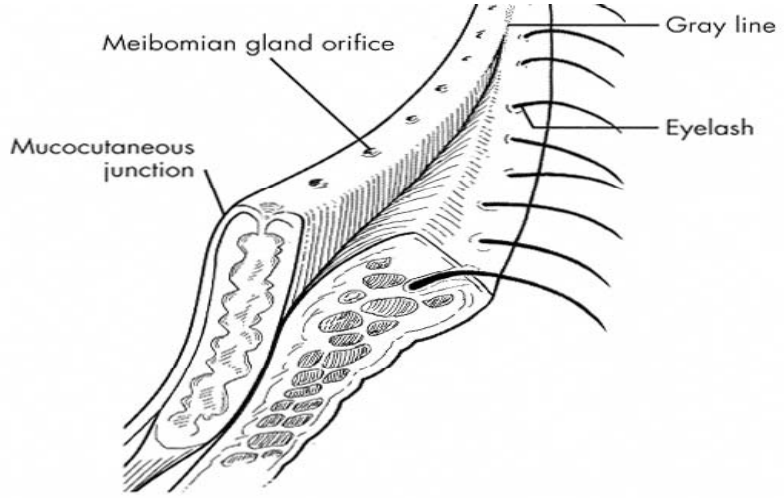


Fig. 2-5 The margin reflex distance.

Anatomy

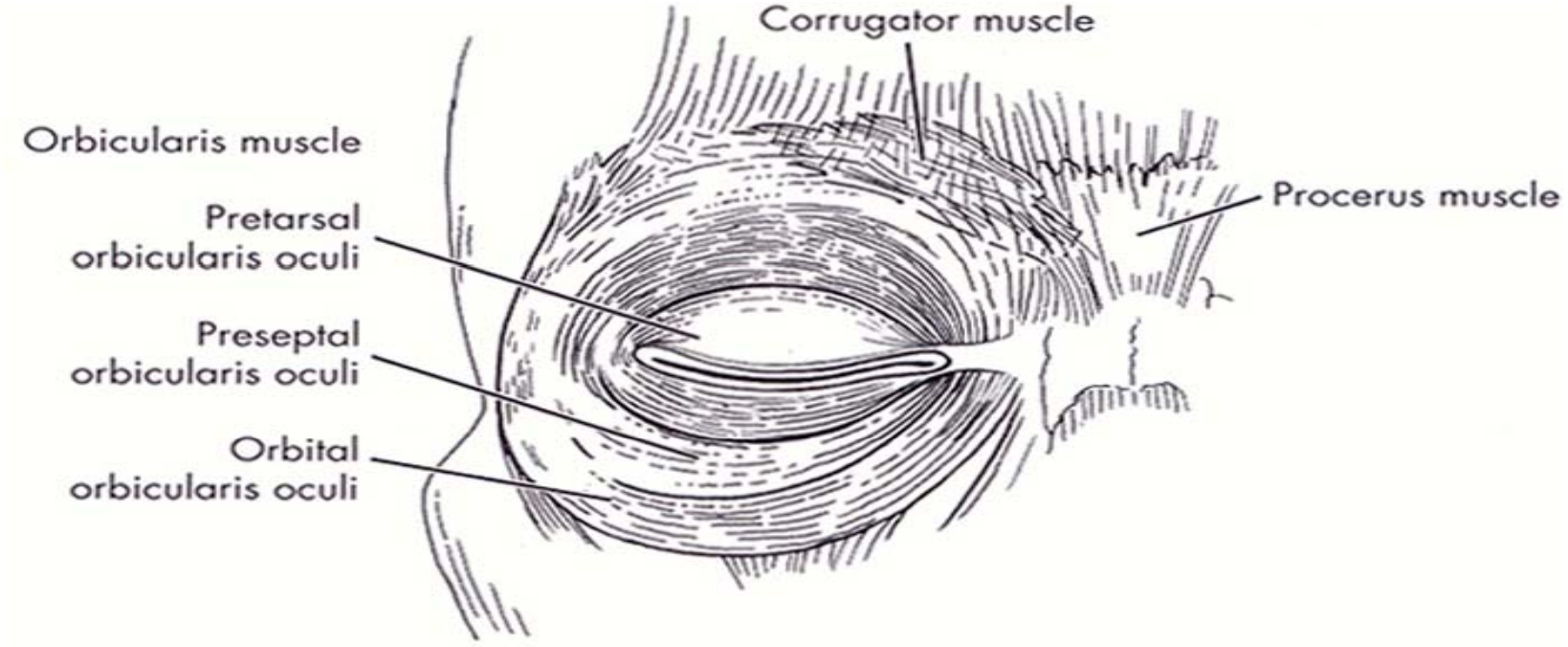
- Tarsus
  - Dense, fibrous tissue
  - Contour and skeleton
  - Contain meibomian glands
  - Length – 25 mm
  - Thickness – 1 mm
  - Height
    - Upper plate – 10 mm
    - Lower plate – 4 mm



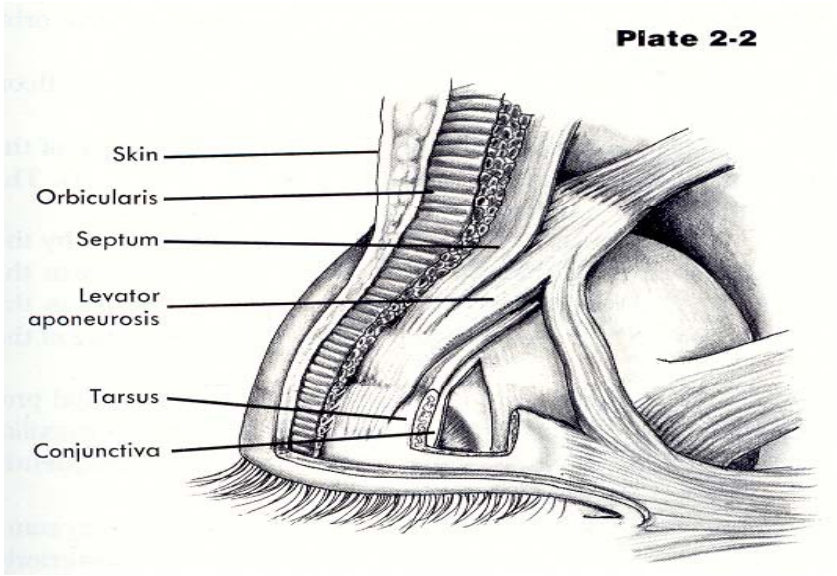
Anatomy – Muscles

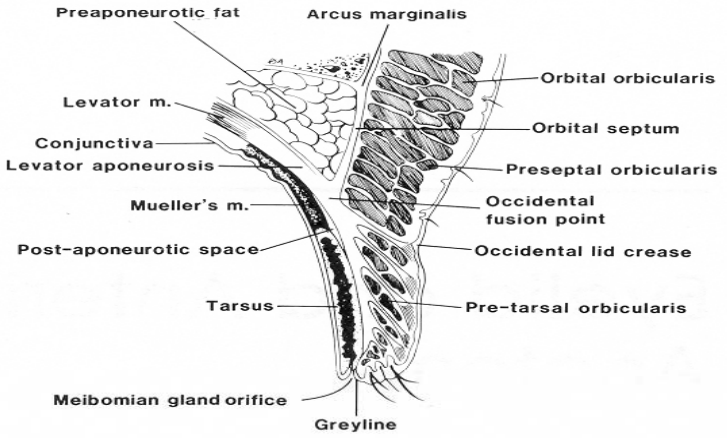
- Protractor
  - Orbicularis
- Retractors
  - Levator
  - Müller's

Orbicularis Oculi Muscle



Levator palpebral superioris and Müller's muscle





Lower Lid Anatomy

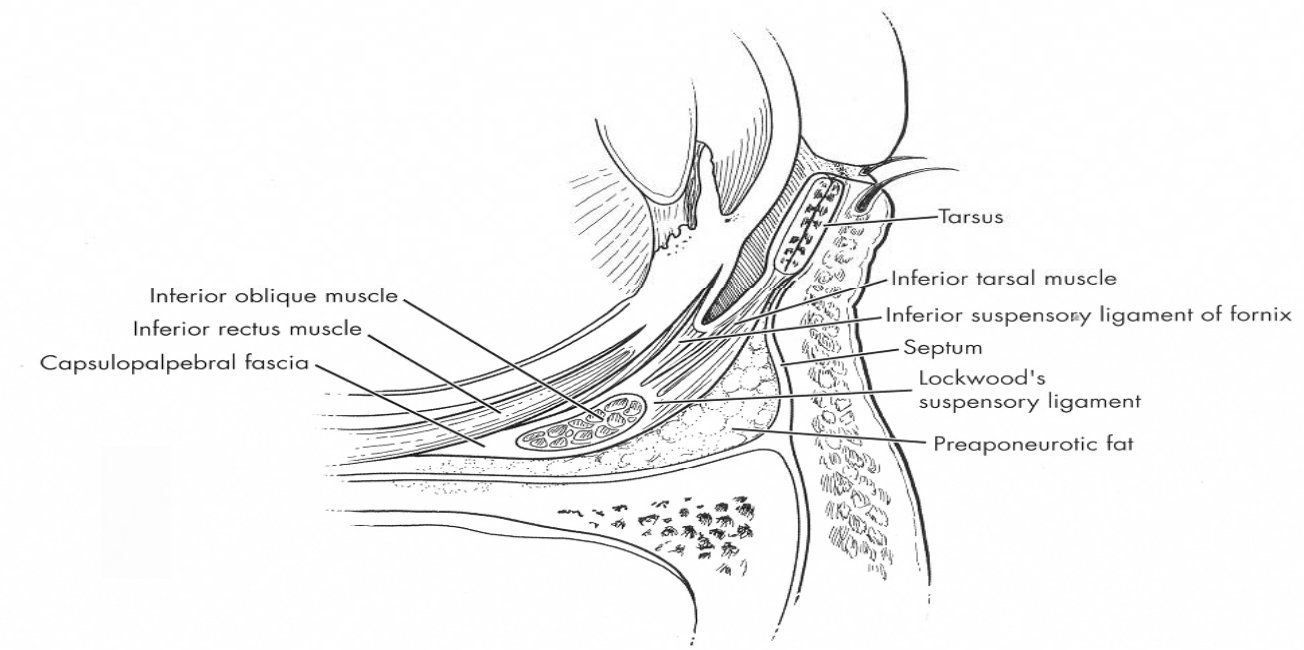
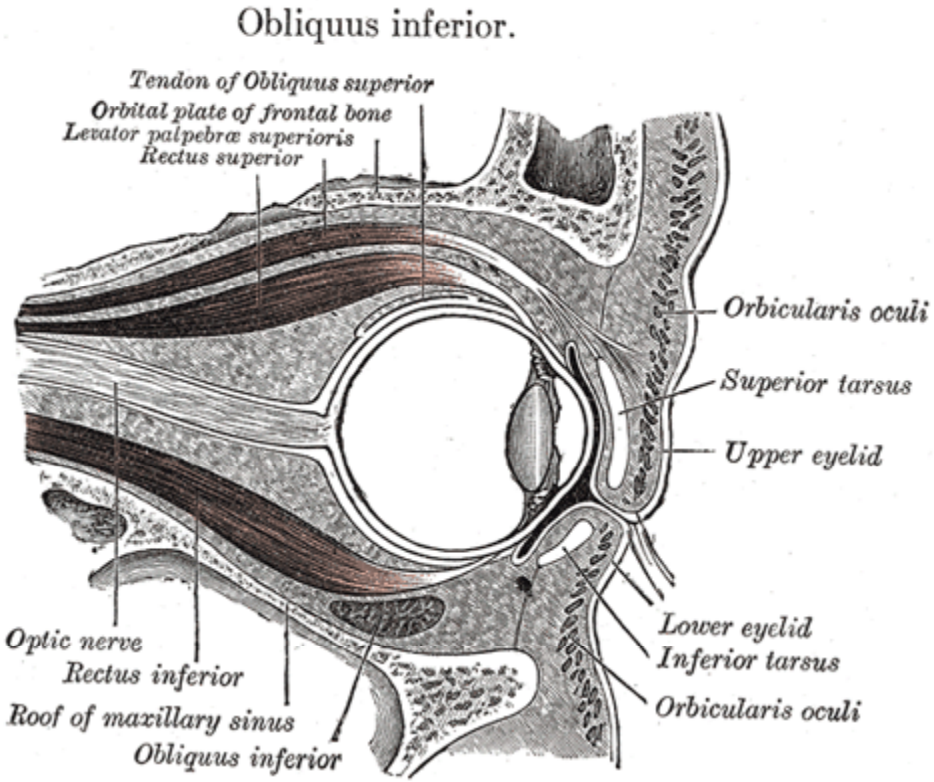


Fig. 2-28 Cross-section of the lower eyelid retractors.

Anatomy



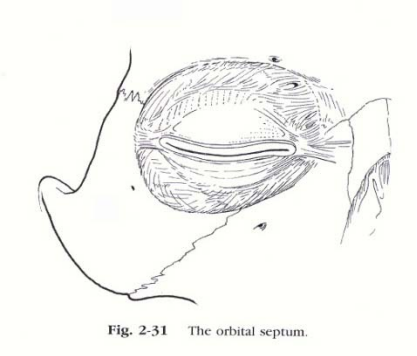
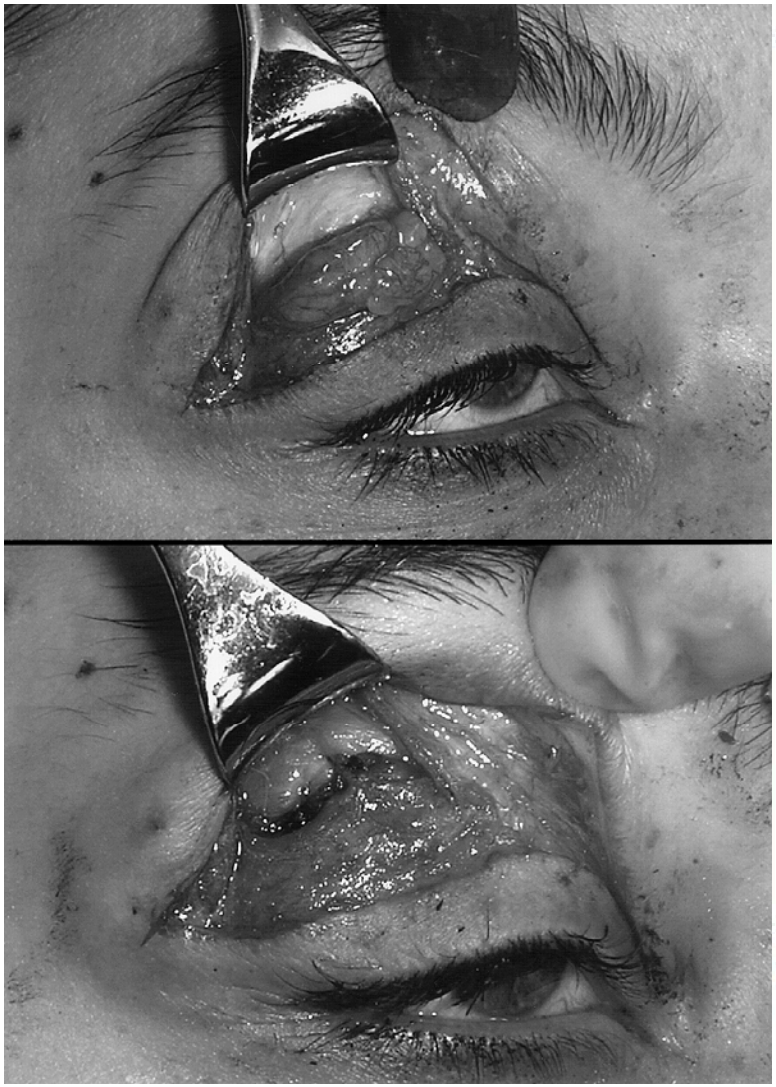


Fig. 2-31 The orbital septum.

- Orbital Septum
  - Fascial barrier
  - Underlies posterior orbicularis fascia
  - Defines anterior extent of orbit and posterior extent of eyelid



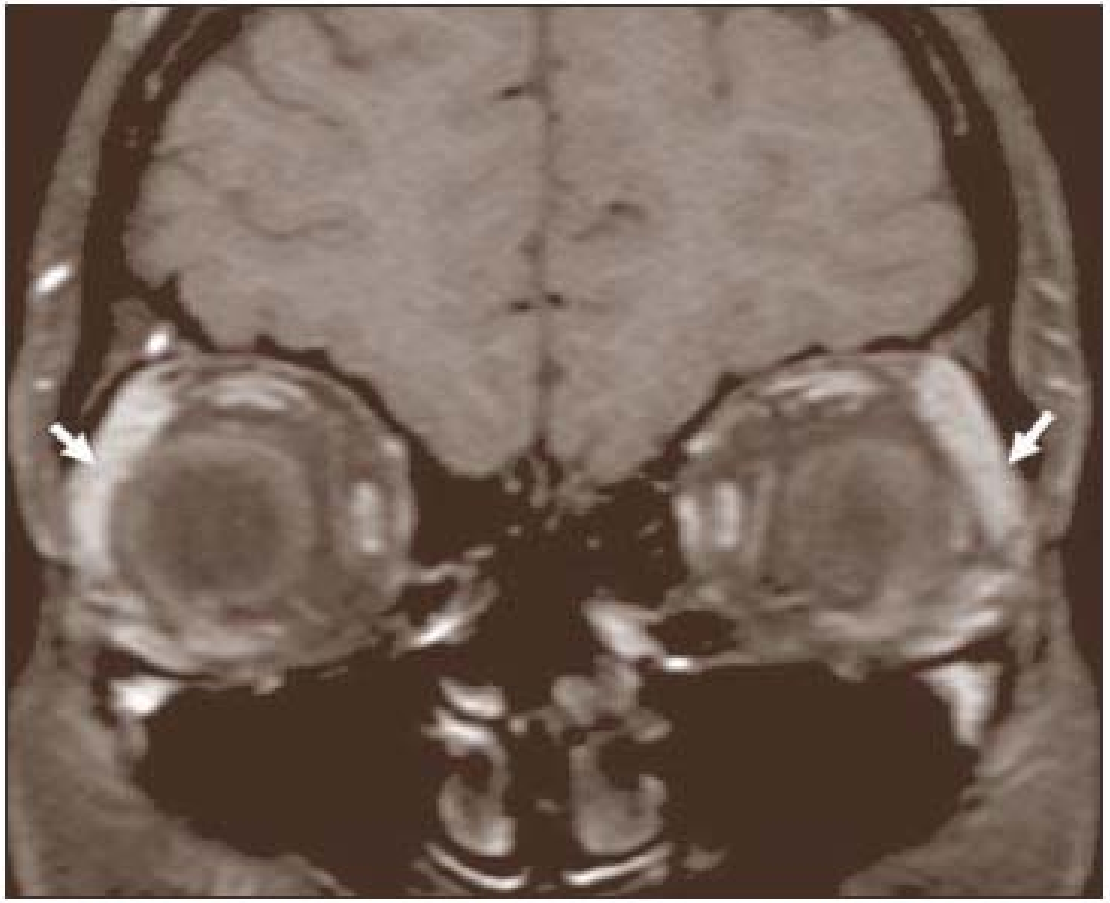
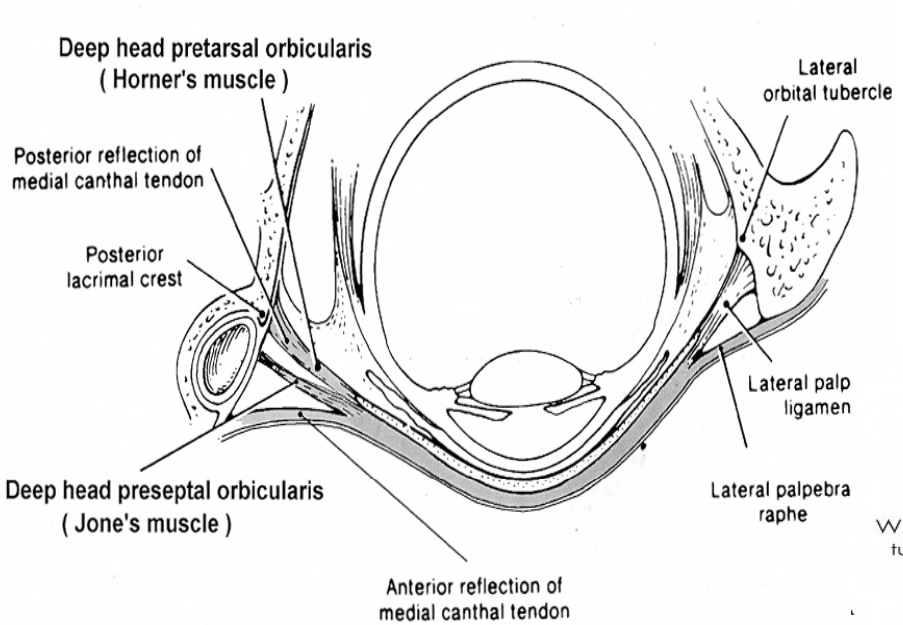


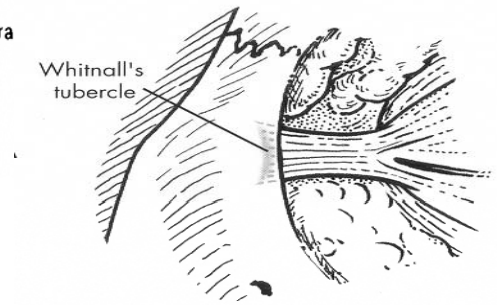
Figure 4. Coronal, SE T1-weighted image with fat suppression after paramagnetic contrast injection: lacrimal glands thickening and prolapse (arrows).

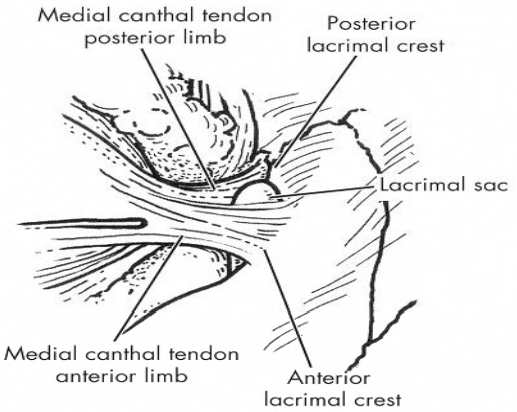
Anatomy

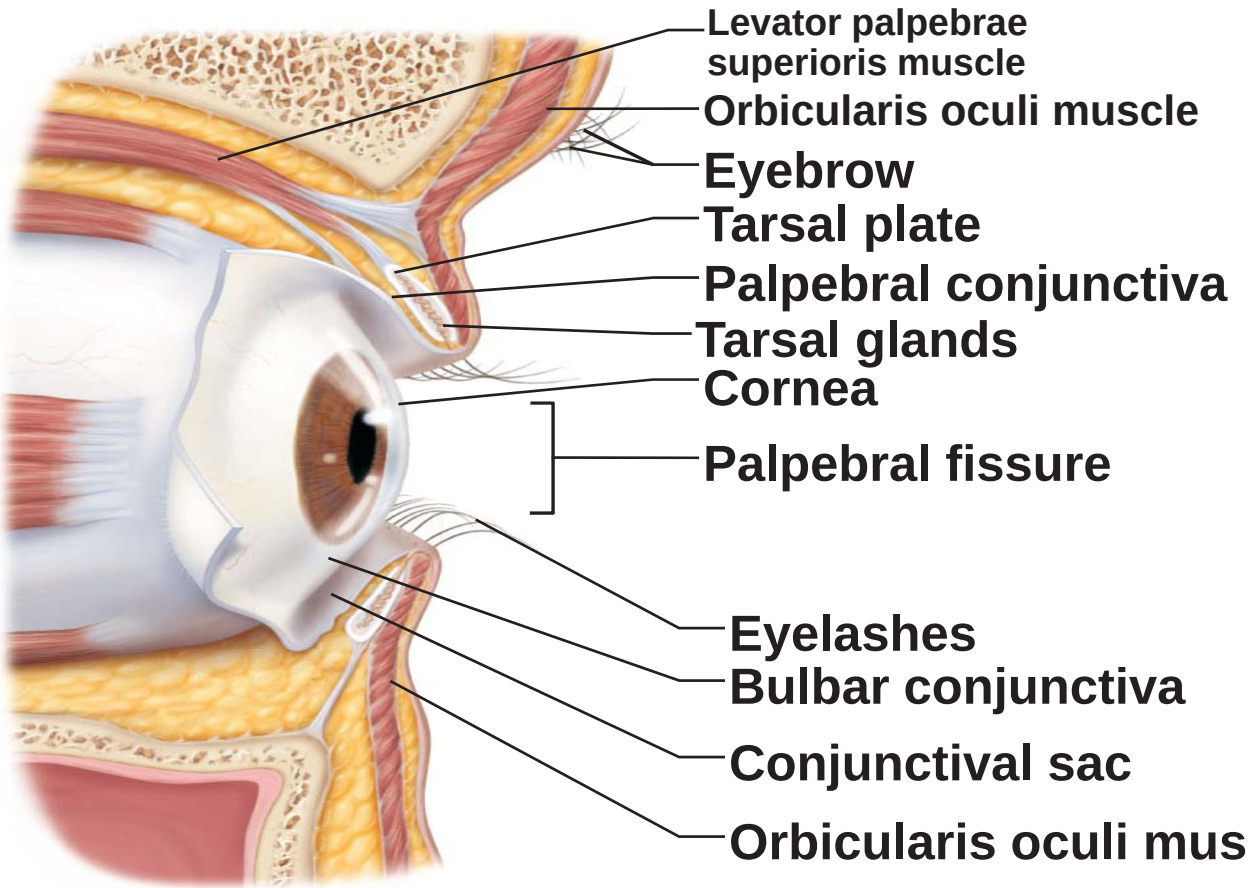
- Canthal tendons
  - Extensions of preseptal & pretarsal orbicularis
  - Lateral slightly above medial
  - Lateral tendon attaches to Whitnall's tubercle 1.5 cm posterior to orbital rim
  - Medial tendon complex, important for lacrimal pump function

Canthal Tendons







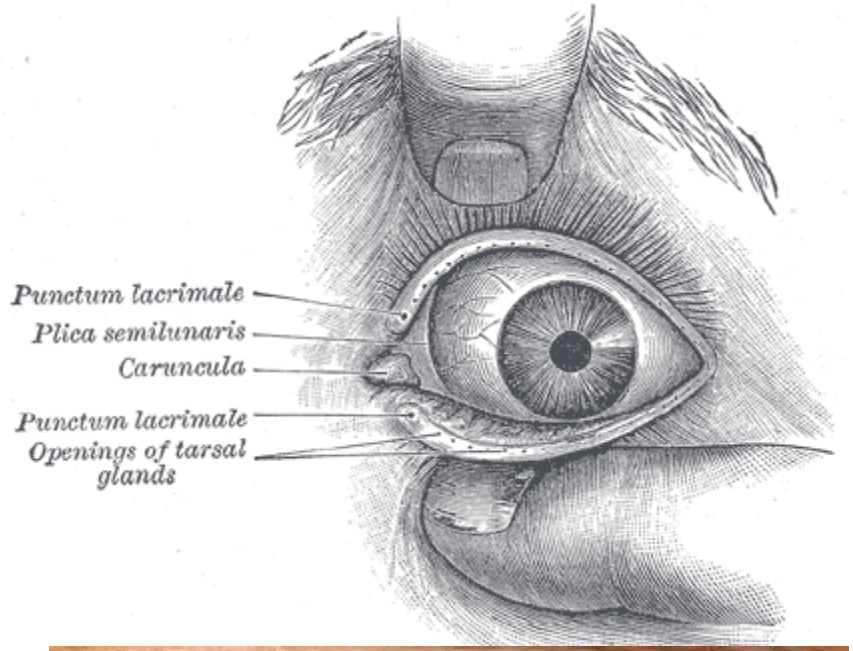


(b) Lateral view; **some structures shown in sagittal section**

Figure 15.1b

Conjunctiva

- Transparent membrane
  - Palpebral conjunctiva lines the eyelids
  - Bulbar conjunctiva covers the white of the eyes
  - Produces a lubricating mucous secretion



Lacrimal Apparatus

- Lacrimal gland and ducts that connect to nasal cavity
- Lacrimal secretion (tears)
  - Dilute saline solution containing mucus, antibodies, and lysozyme
  - Blinking spreads the tears toward the medial commissure
  - Tears enter paired lacrimal canaliculi via the lacrimal puncta
  - Drain into the nasolacrimal duct

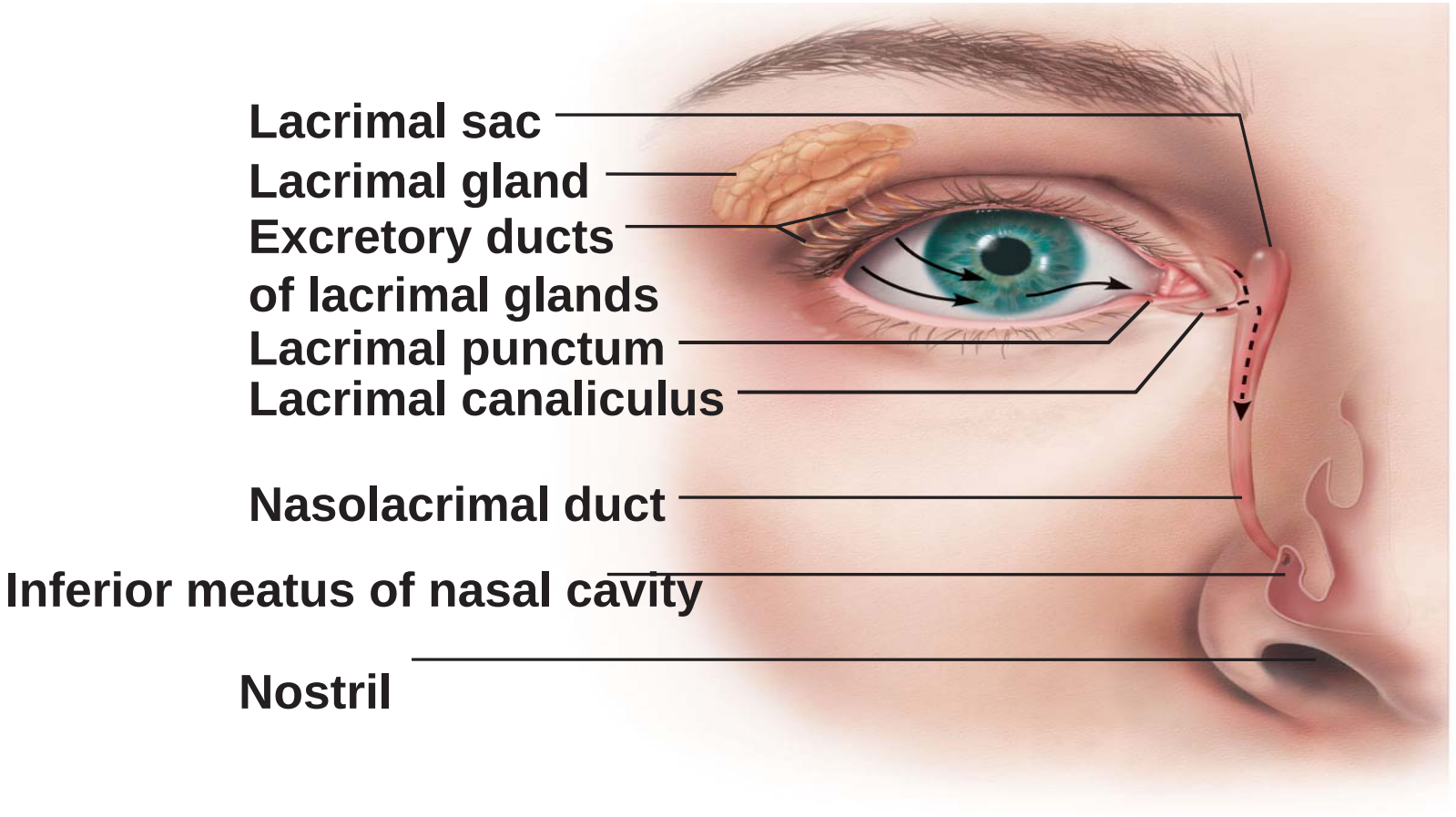

Lacrimal sac
Lacrimal gland
Excretory ducts
of lacrimal glands
Lacrimal punctum
Lacrimal canaliculus
Nasolacrimal duct
Inferior meatus of nasal cavity
Nostril

Figure 15.2

Accessory Structures of the Eye

- Lacrimal apparatus – keeps the surface of the eye moist
  - Lacrimal gland – produces lacrimal fluid
  - Lacrimal sac – fluid empties into nasal cavity

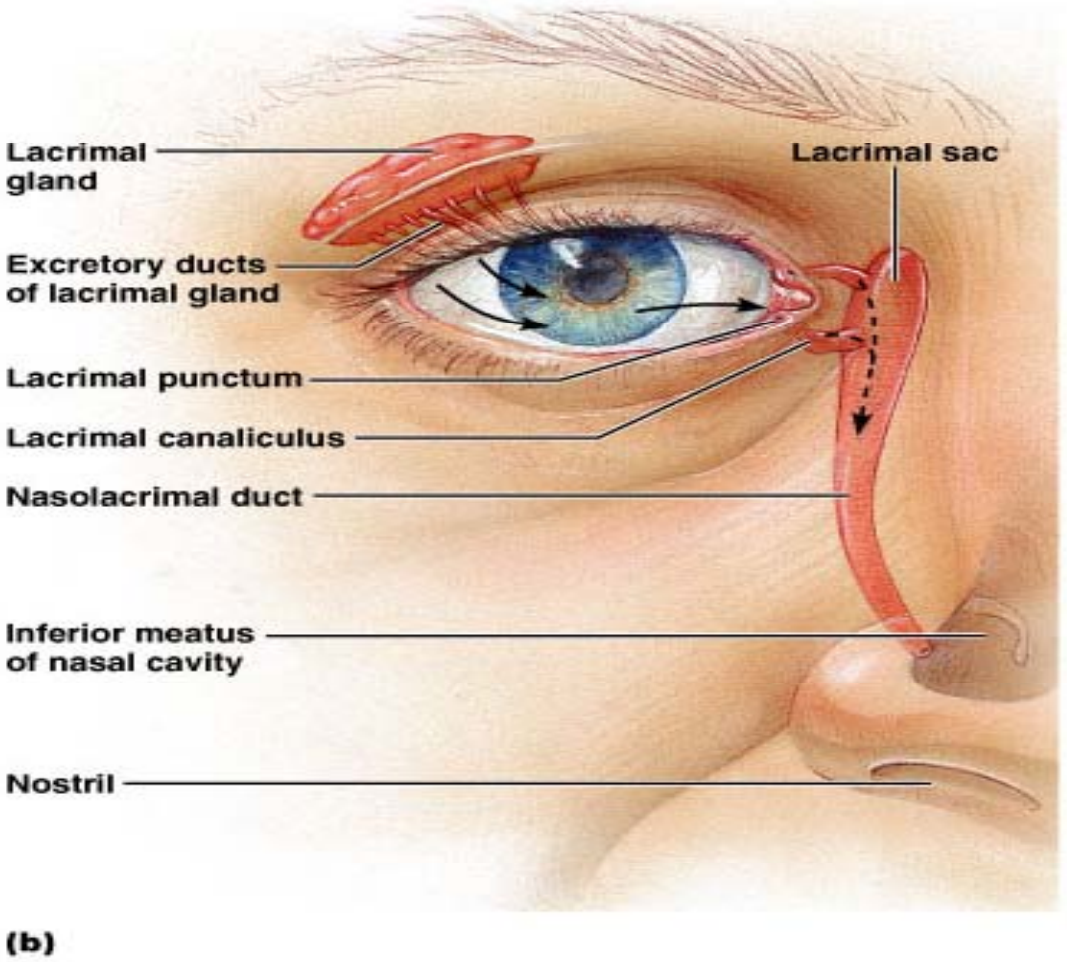
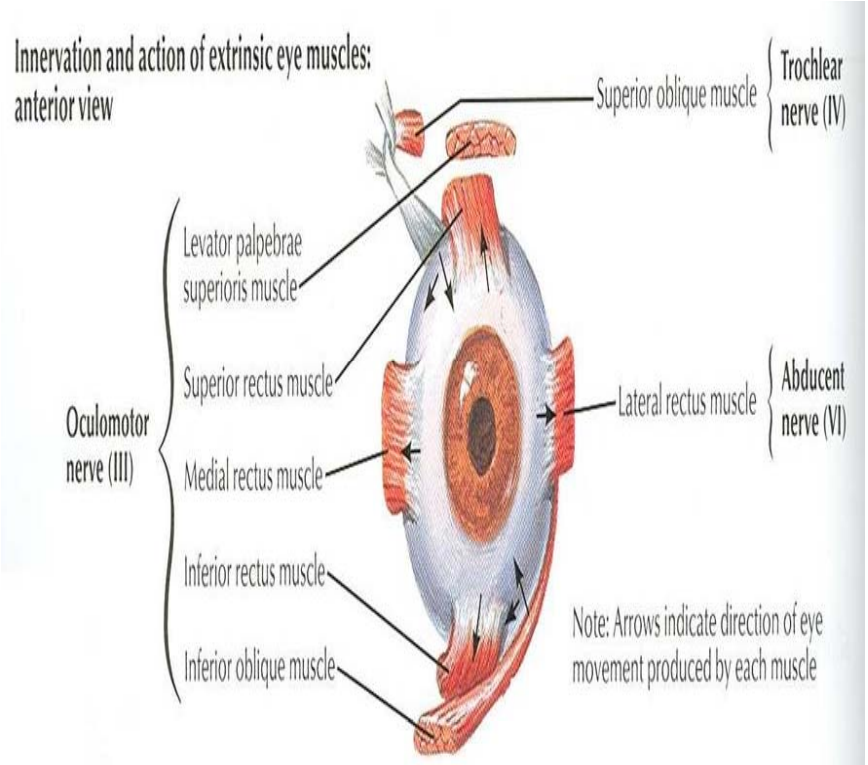
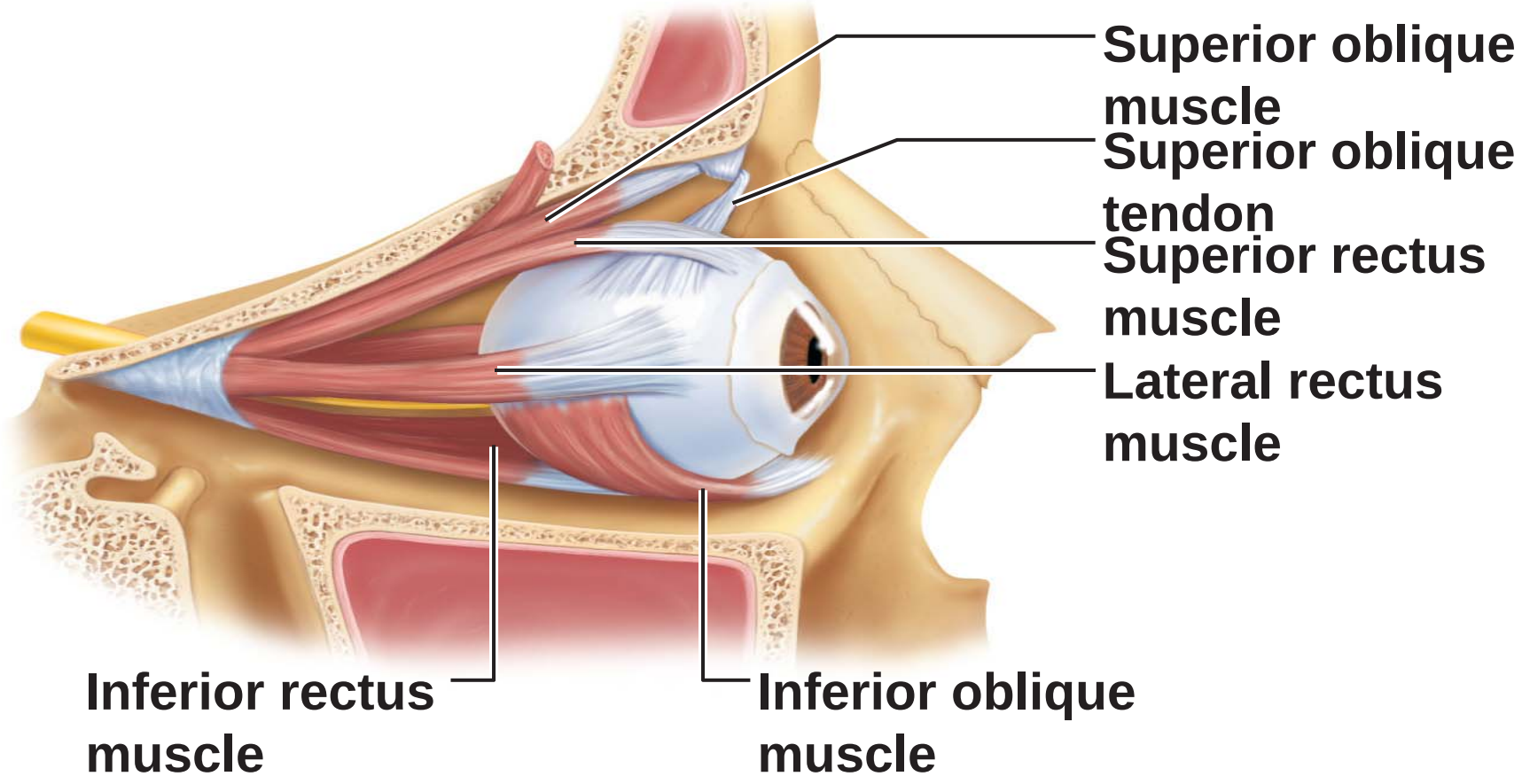


Figure 16.5b

Extrinsic Eye Muscles

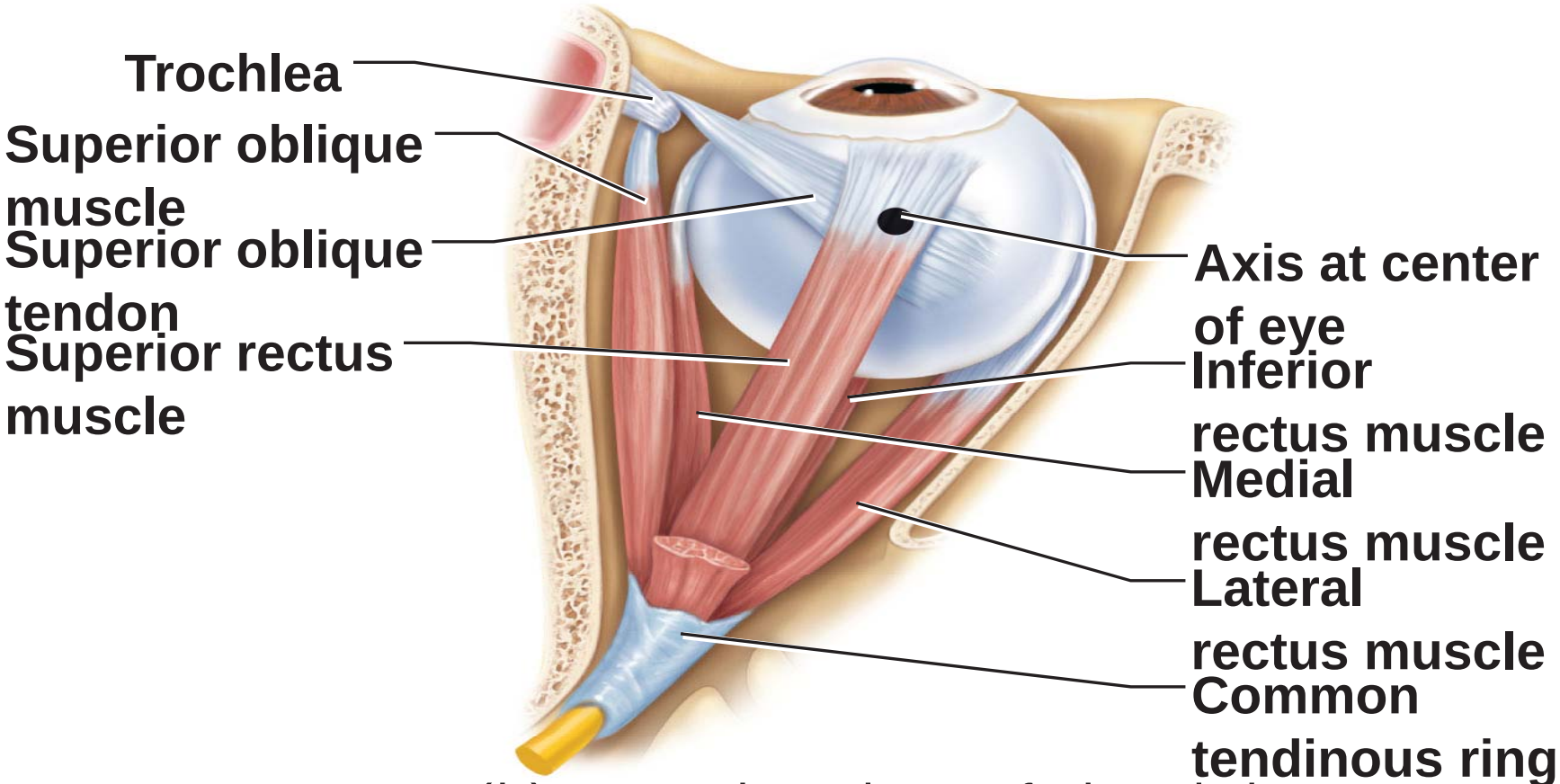
- Six straplike extrinsic eye muscles
  - Originate from the bony orbit
  - Enable the eye to follow moving objects
  - Maintain the shape of the eyeball
- Four rectus muscles originate from the common tendinous ring; names indicate the movements they promote
- Two oblique muscles move the eye in the vertical plane and rotate the eyeball





(a) Lateral view of the right eye

Figure 15.3a



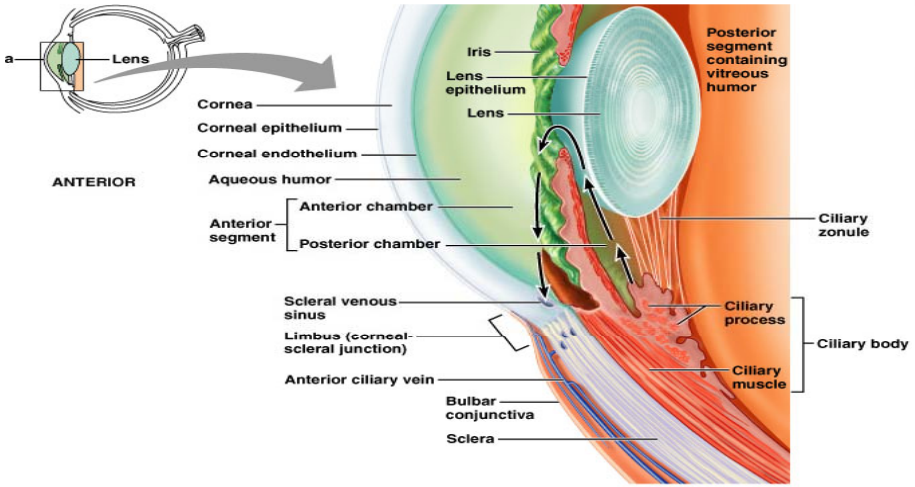
(b) Superior view of the right eye

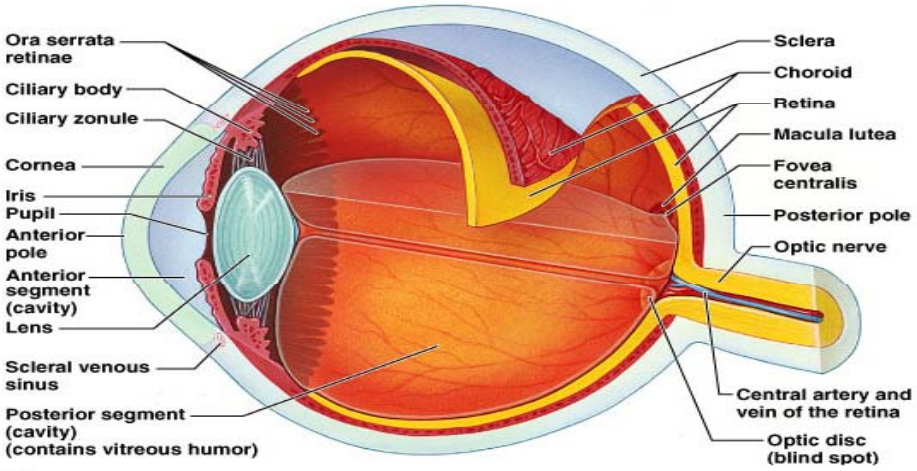
Figure 15.3b

- Double vision: ***diplopia*** (what the patient experiences)
  - Eyes do not look at the same point in the visual field
- Misalignment: ***strabismus*** (what is observed when shine a light: not reflected in the same place on both eyes) – can be a cause of diplopia
  - Cross eyed
  - Gaze & movements not conjugate (together)
  - Medial or lateral, fixed or not
  - Many causes
    - Weakness or paralysis of extrinsic muscle of eye
      - ***Surgical correction necessary***
    - Oculomotor nerve problem, other problems
- Lazy eye: ***amblyopia***
  - Cover/uncover test at 5 yo
  - If don't patch good eye by 6, brain ignores lazy eye and visual pathway degenerates: eye functionally blind

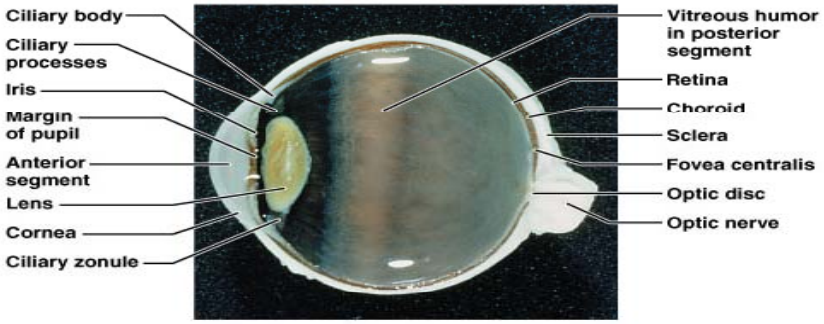
NOTE: some neurological development and connections have a window of time - need stimuli to develop, or ability lost

ome pictures…



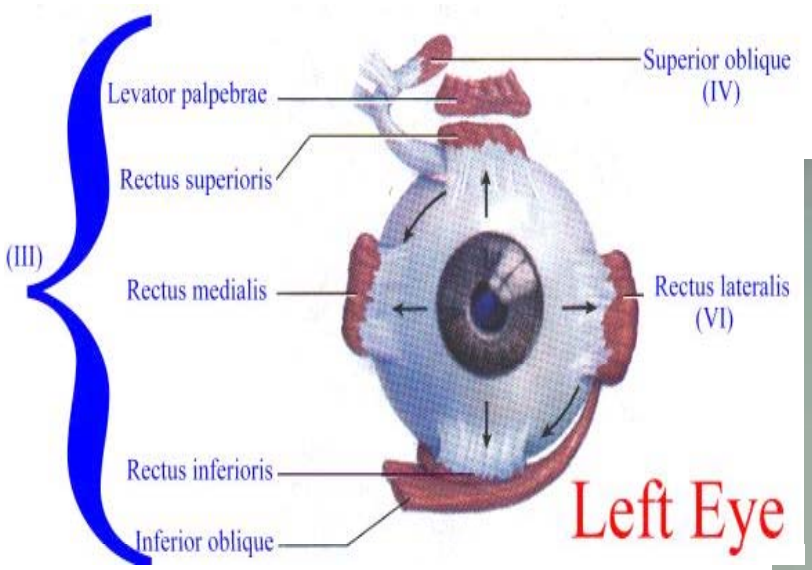


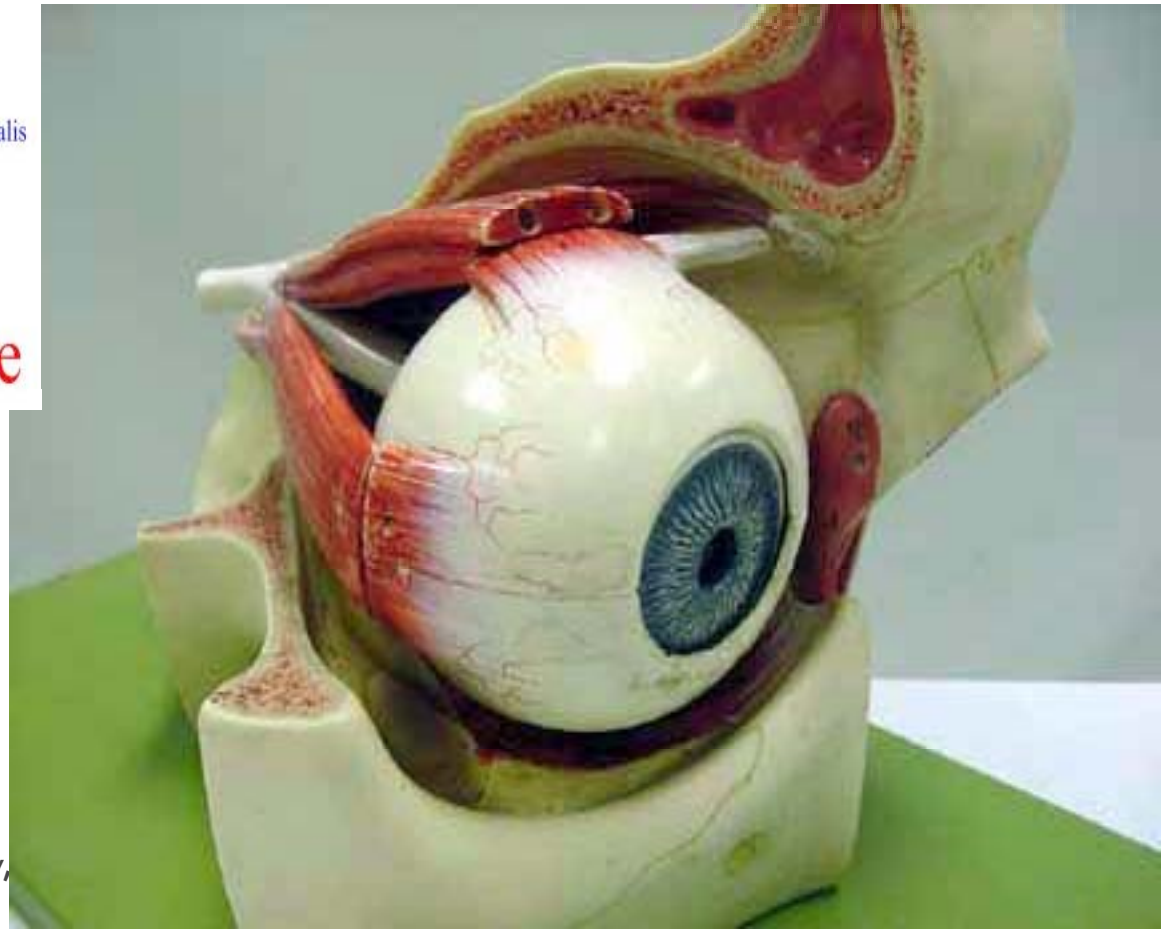
(a)



(b)

Movement of eye

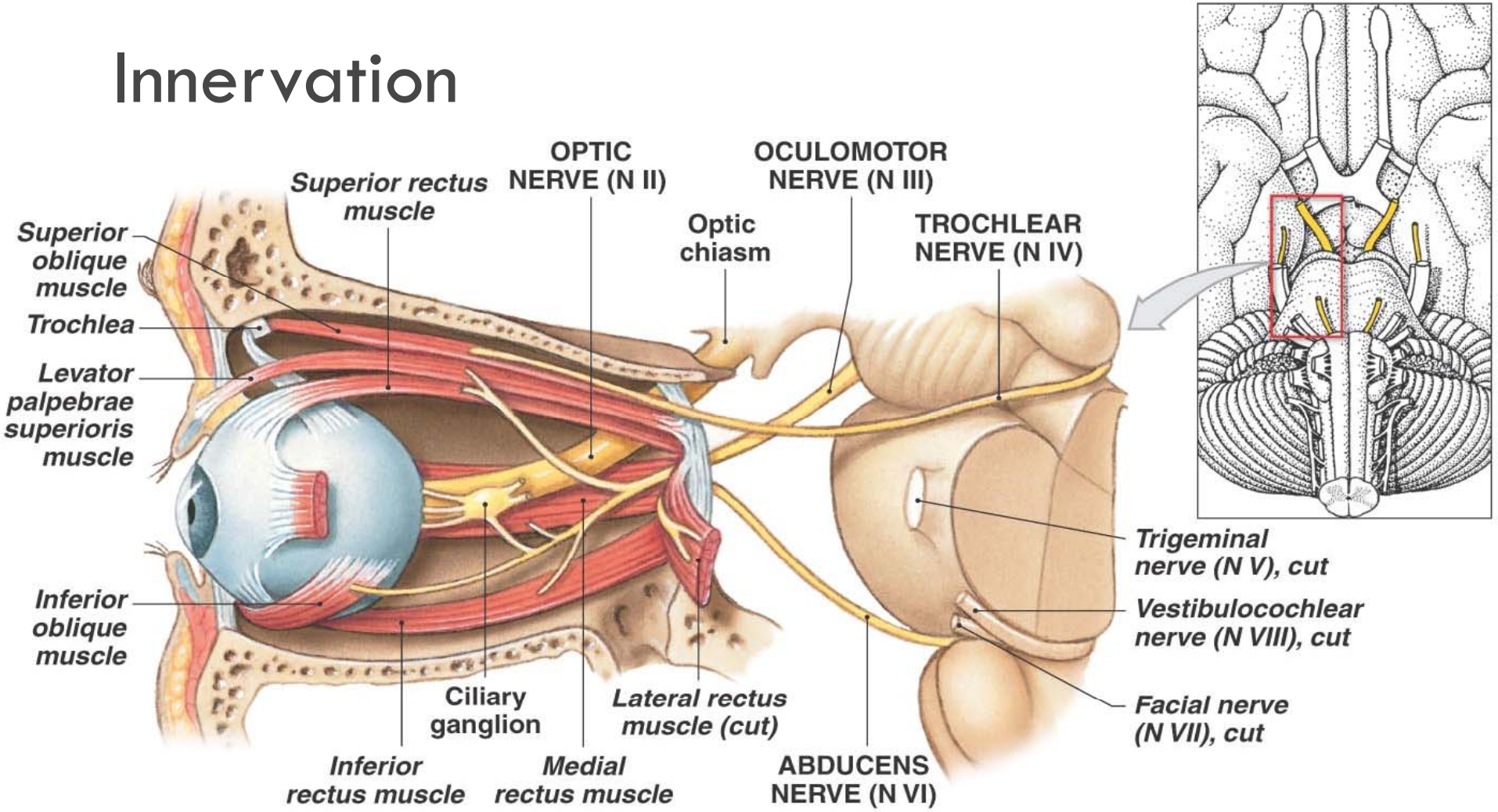




Eye movement simulator (http://cim.ucdavis.edu/eyes/version1/eyesim.htm)

Human Anatomy,

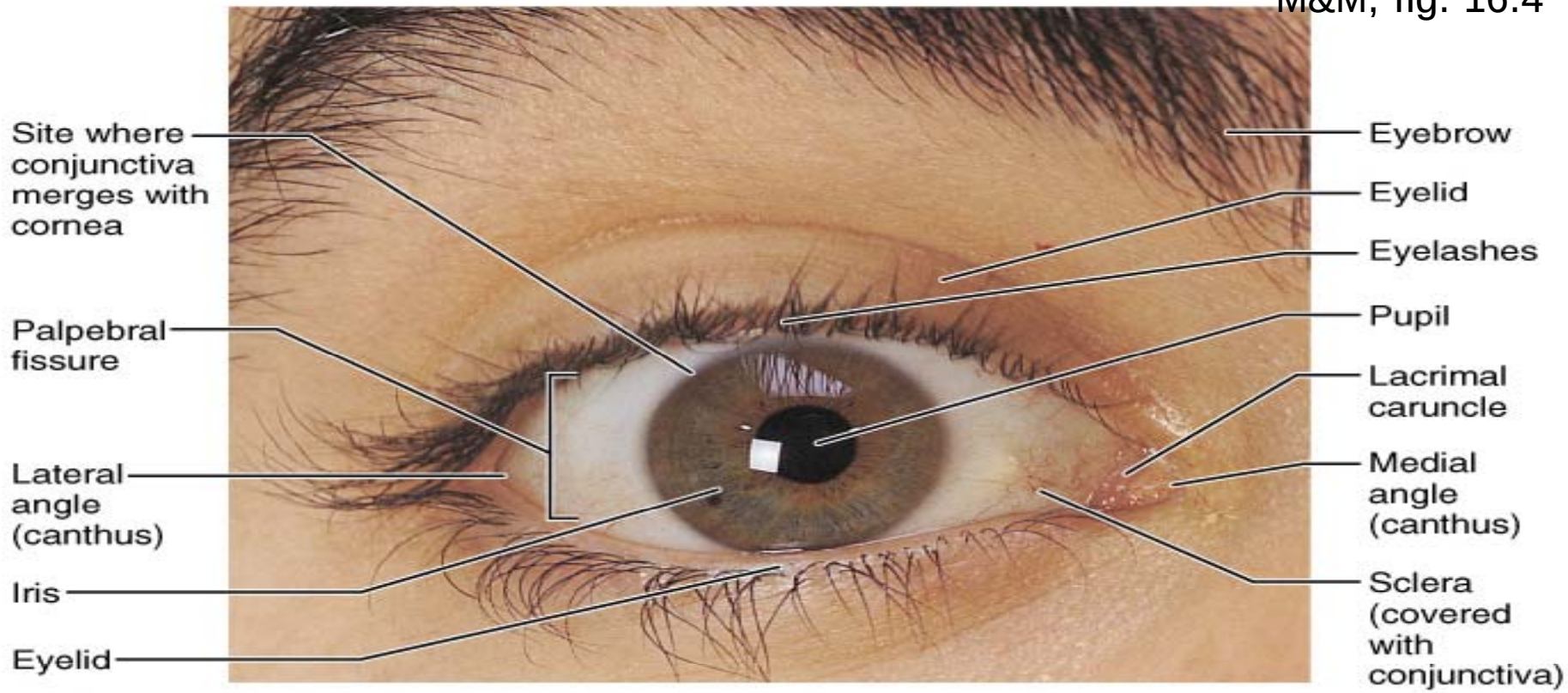
Innervation



Extrinsic eye muscles

Muscle	**Movement**	**Nerve**
Superior oblique	Depresses eye, turns laterally	IV (Trochlear)
Lateral rectus	Turns laterally	VI (Abducens)
Medial rectus	Turns medially	III (Oculomotor)
Superior rectus	Elevates	III (Oculomotor)
Inferior rectus	Depresses eye	III (Oculomotor)
Inferior oblique	Elevates eye, turns laterally	III (Oculomotor)

M&M, fig. 16.4



Muscle	Action	Controlling cranial nerve
Lateral rectus	**Moves eye laterally**	**VI (abducens)**
Medial rectus	**Moves eye medially**	**III (oculomotor)**
Superior rectus	**Elevates eye and turns it medially**	**III (oculomotor)**
Inferior rectus	**Depresses eye and turns it medially**	**III (oculomotor)**
Inferior oblique	**Elevates eye and turns it laterally**	**III (oculomotor)**
Superior oblique	**Depresses eye and turns it laterally**	**IV (trochlear)**

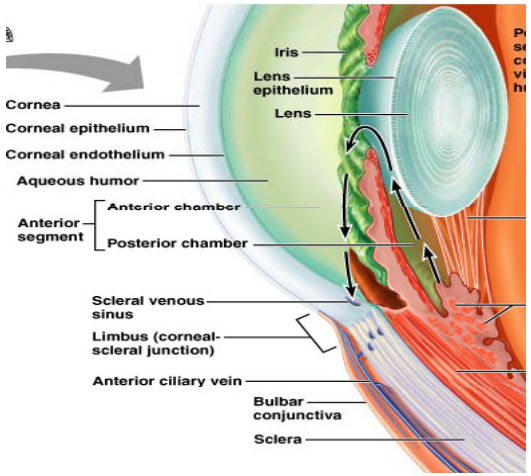
(c) Summary of muscle actions and innervating cranial nerves

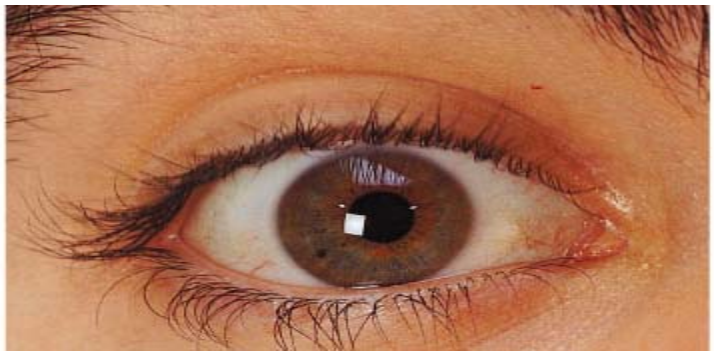
Structure of the Eyeball

- Wall of eyeball contains three layers
  - Fibrous
  - Vascular
  - Sensory
- Internal cavity is filled with fluids called humors
- The lens separates the internal cavity into anterior and posterior segments (cavities)

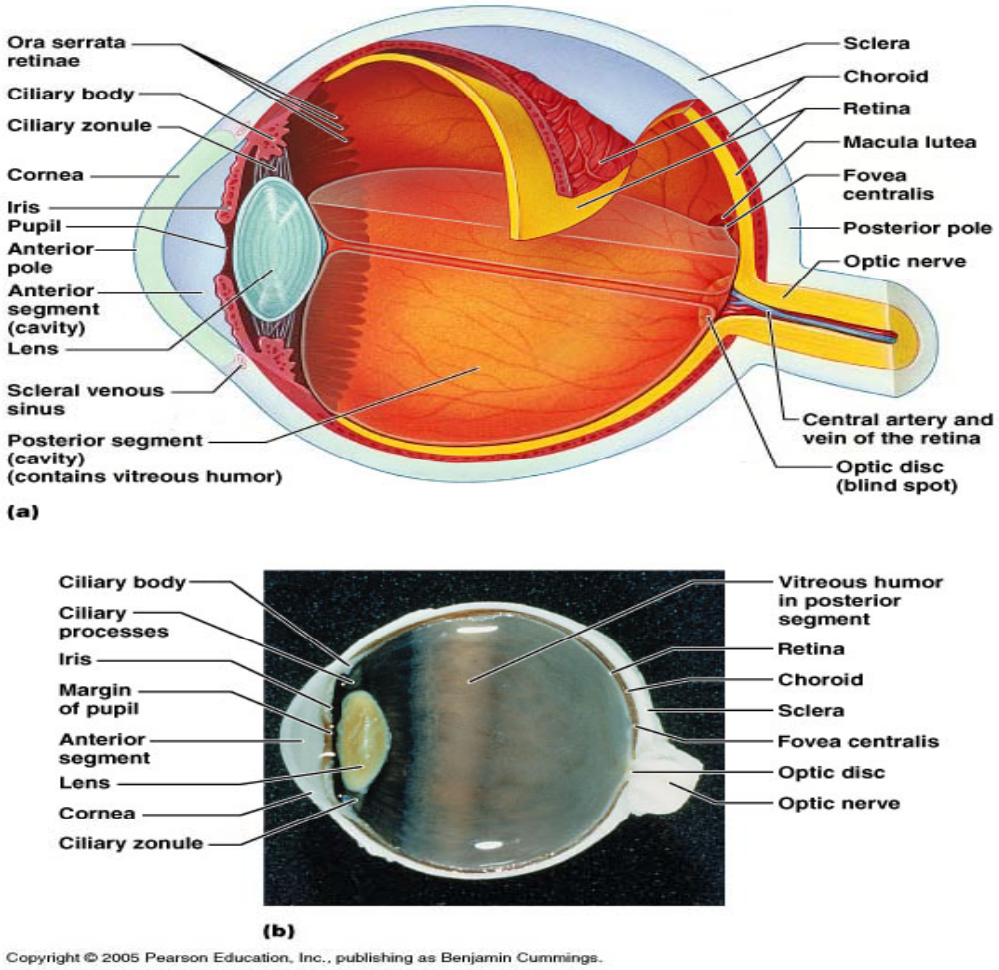
3 Layers form the external wall of the eye

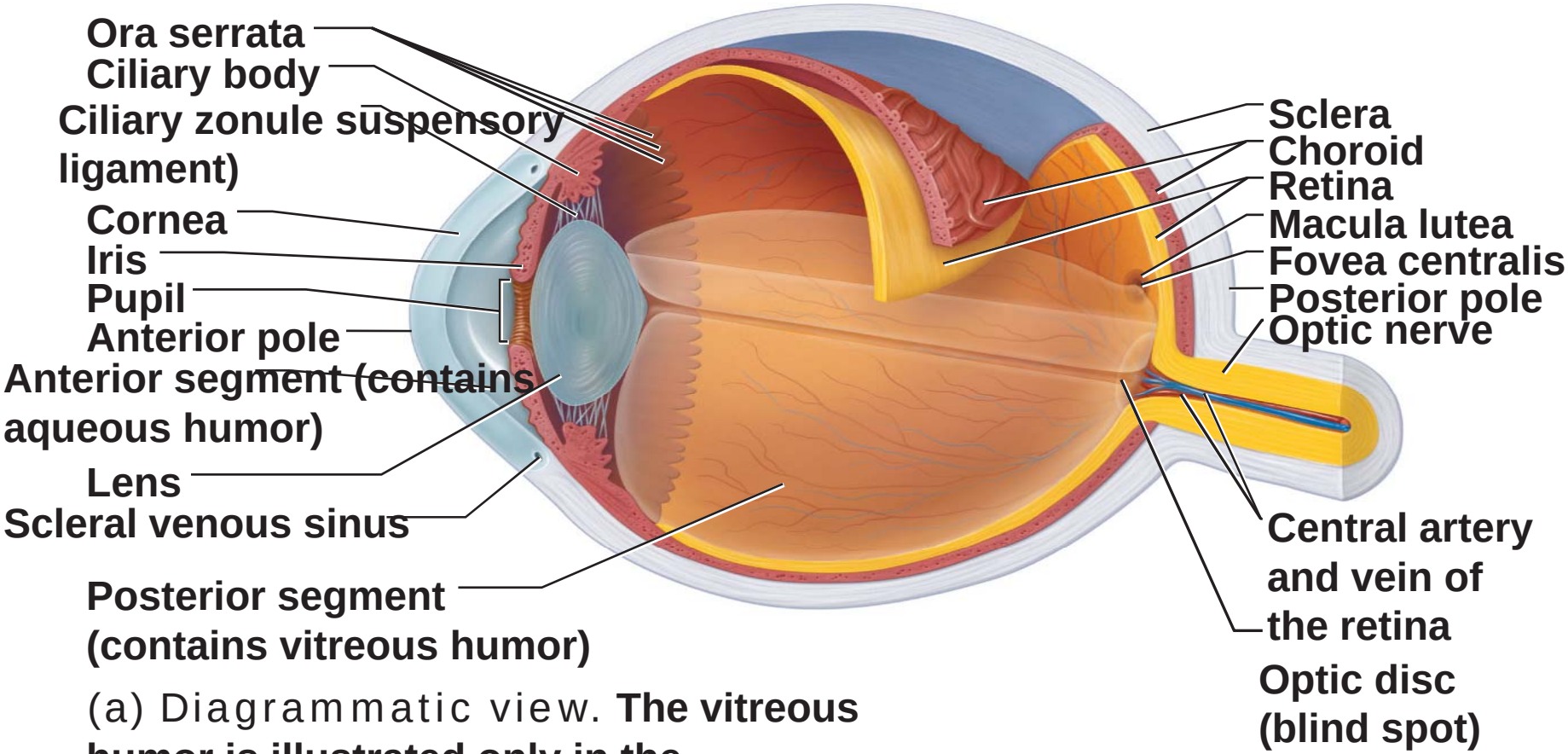
1. (outer) Fibrous: dense connective tissue
   - ***Sclera*** – white of the eye
   - ***Cornea***
     - 100s of sheets of collagen fibers between sheets of epithelium and endothelium
     - Clear because regular alignment
     - Role in light bending
     - Avascular but does have pain receptors
     - Regenerates
2. (middle) Vascular: ***uvea***
   - ***Choroid*** – posterior, pigmented
   - ***Ciliary body***
   - ***Iris (colored part: see next slide)***
3. (inner) Sensory
   - ***Retina and optic nerve***





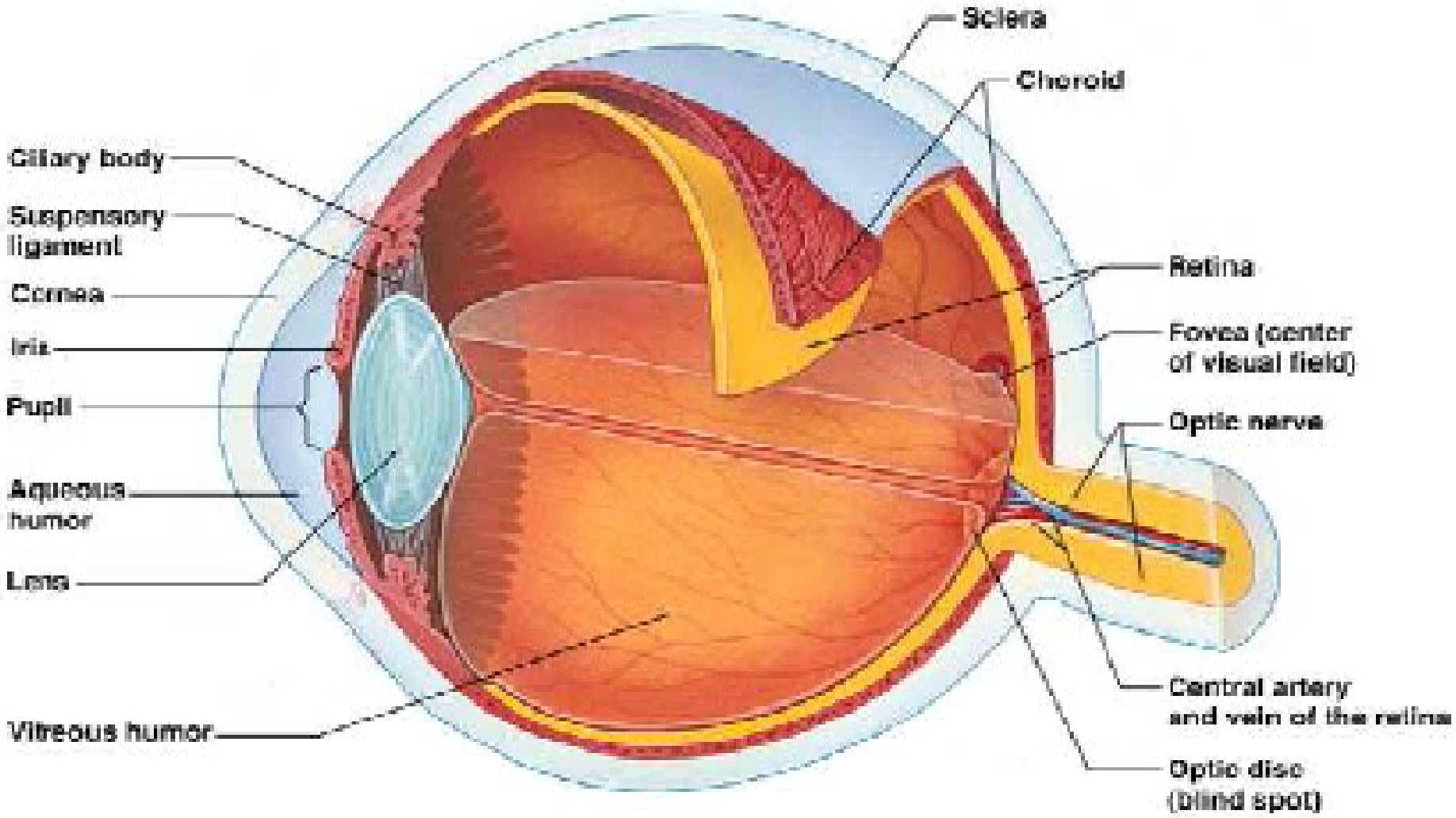
1. (outer layer) Fibrous: dense connective tissue
   - ***Sclera*** – white of the eye
   - ***Cornea***
2. (middle) Vascular: uvea
   - ***Choroid*** – posterior, pigmented
   - ***Ciliary body***
     - Muscles – control lens shape
     - Processes – secrete aqueous humor
     - Zonule (attaches lens)
   - ***Iris***
3. (inner layer) Sensory
   - ***Retina and optic nerve***





(a) Diagrammatic view. **The vitreous humor is illustrated only in the bottom part of the eyeball.**

Figure 15.4a


Sclera
Choroid
Ciliary body
Suspensory ligament
Cornea
Iris
Pupil
Aqueous humor
Lens
Vitreous humor
Retina
Fovea (center of visual field)
Optic nerve
Central artery and vein of the retina
Optic disc (blind spot)

Posterior View of the Anterior Half of the Eye

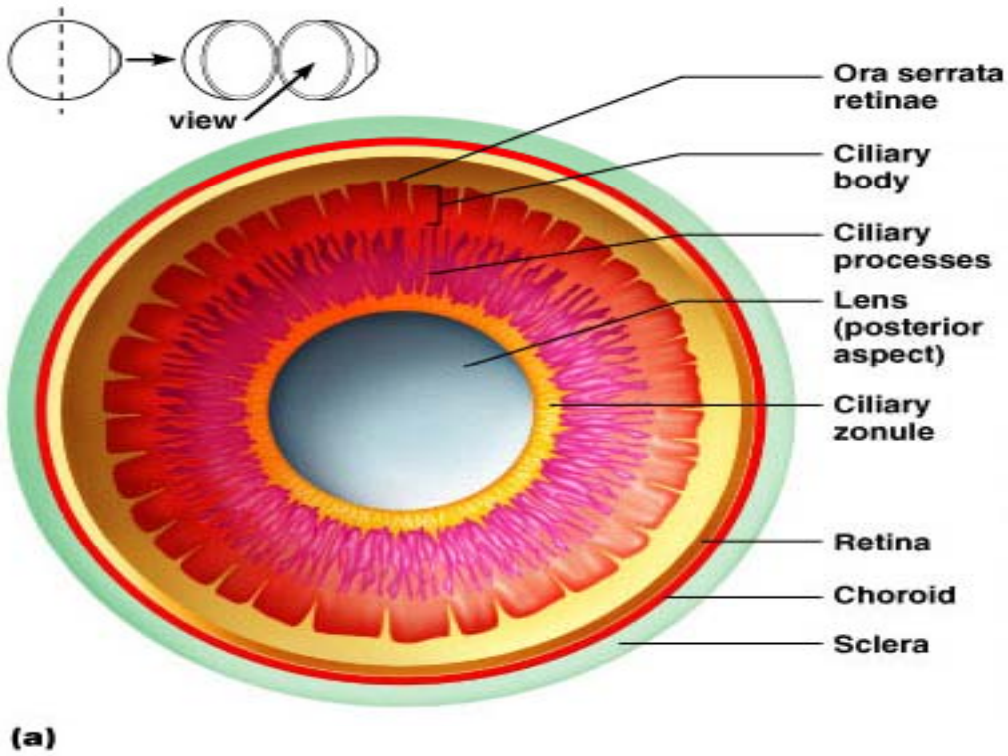
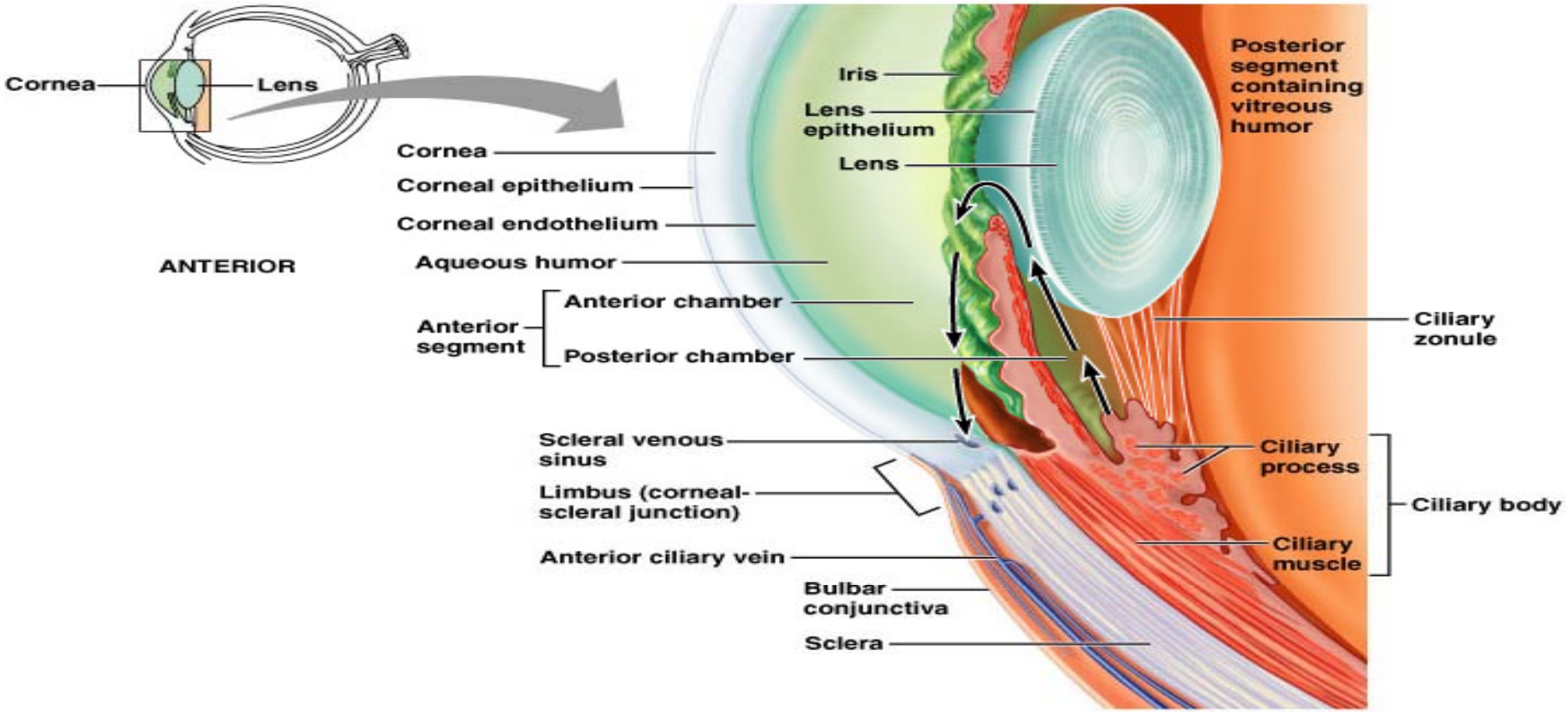


Figure 16.9a

The Vascular Tunic



Fibrous Layer

- Outermost layer; dense avascular connective tissue
- Two regions: sclera and cornea

1. Sclera
   - Opaque posterior region
   - Protects and shapes eyeball
   - Anchors extrinsic eye muscles

Fibrous Layer

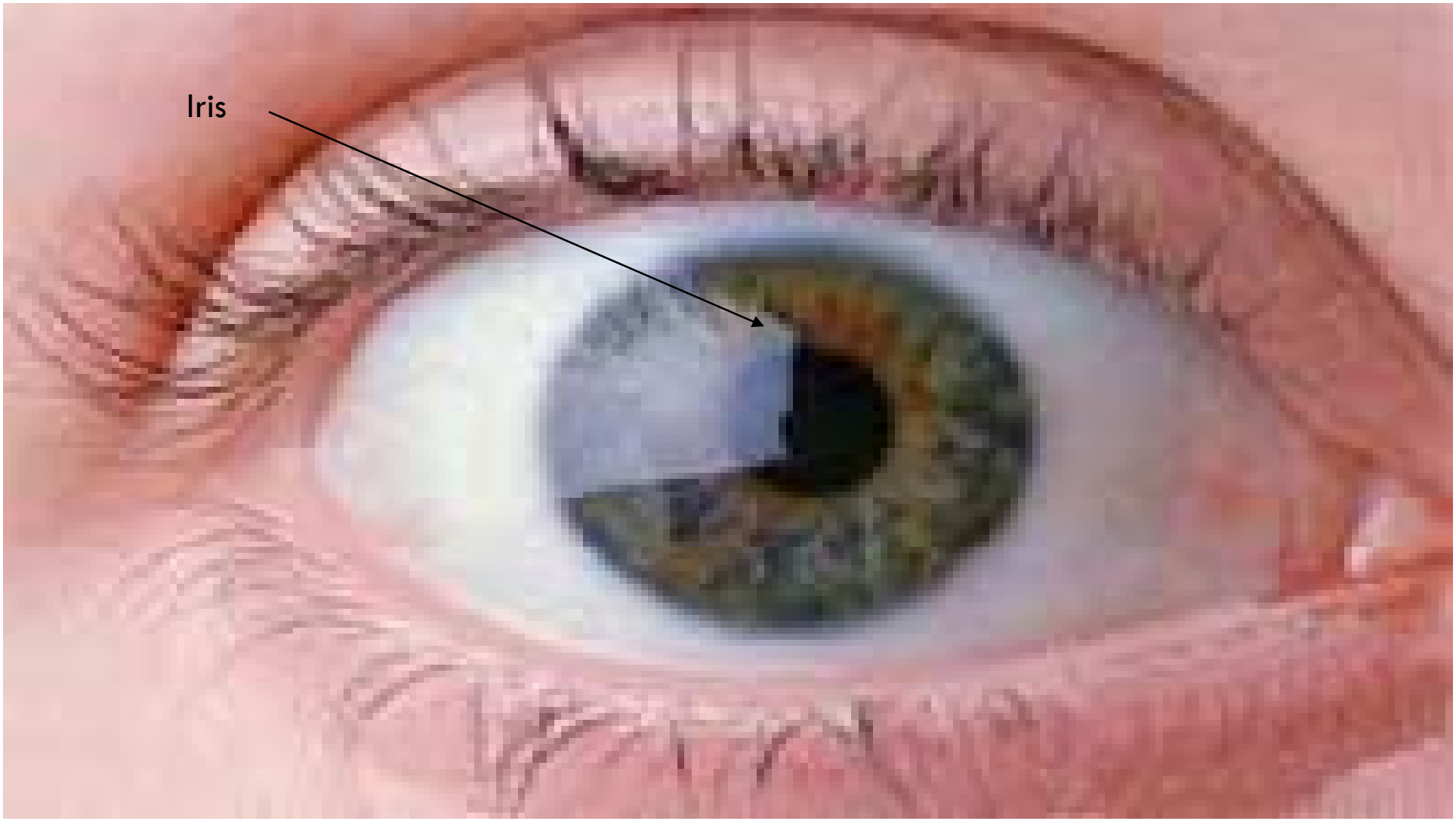
2. Cornea:
   - Transparent anterior 1/6 of fibrous layer
   - Bends light as it enters the eye
   - Sodium pumps of the corneal endothelium on the inner face help maintain the clarity of the cornea
   - Numerous pain receptors contribute to blinking and tearing reflexes

Vascular Layer (Uvea)

- Middle pigmented layer
- Three regions: choroid, ciliary body, and iris
  1. Choroid region
     - Posterior portion of the uvea
     - Supplies blood to all layers of the eyeball
     - Brown pigment absorbs light to prevent visual confusion

Vascular Layer

2. Ciliary body
   - Ring of tissue surrounding the lens
   - Smooth muscle bundles (ciliary muscles) control lens shape
   - Capillaries of ciliary processes secrete fluid
   - Ciliary zonule (suspensory ligament) holds lens in position

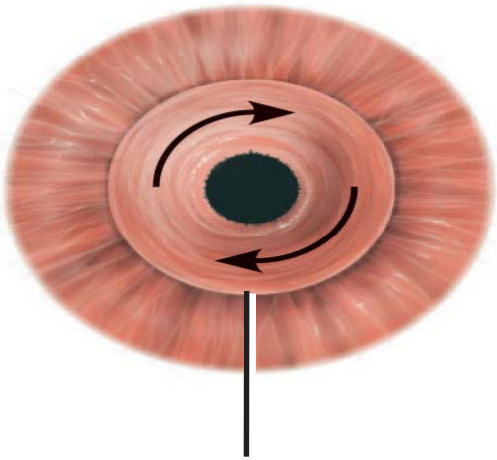

Iris

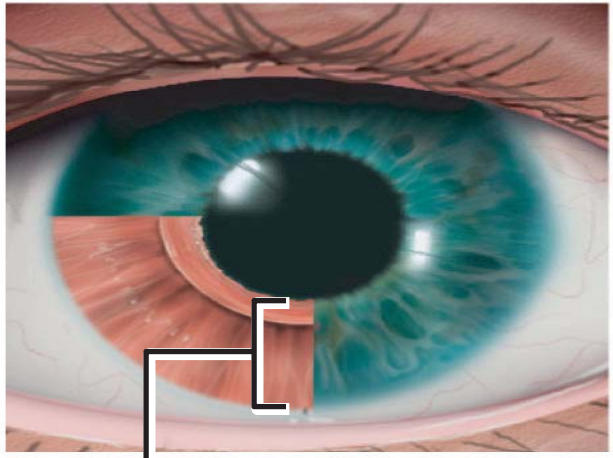
Vascular Layer

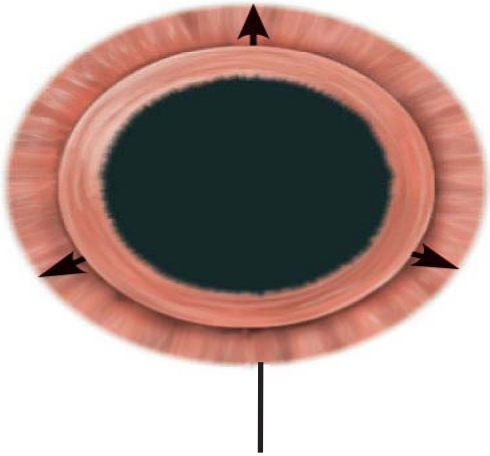
3. Iris
   - The colored part of the eye
     - Pupil—central opening that regulates the amount of light entering the eye
       - Close vision and bright light—sphincter papillae (circular muscles) contract; pupils constrict
       - Distant vision and dim light—dilator papillae (radial muscles) contract; pupils dilate
       - Changes in emotional state—pupils dilate when the subject matter is appealing or requires problem-solving skills

Parasympathetic +

Sympathetic +







Sphincter pupillae muscle contraction decreases pupil size.

Iris (two muscles)

- **Sphincter pupillae**
- **Dilator pupillae**

Dilator pupillae muscle contraction increases pupil size.

Figure 15.5

Retina

- The **retina** is a thin layer of cells at the back of the eyeball of vertebrates.
- It is the part of the eye which converts light into nervous signals.
- The retina contains photoreceptor cells (rods and cones) which receive the light; the resulting neural signals then undergo complex processing by other neurons of the retina, and are transformed into action potentials in retinal ganglion cells whose axons form the optic nerve.
- The retina not only detects light, it also plays a significant part in visual perception.
- In embryonal development, the retina and the optic nerve originate as outgrowths of the brain.
- The unique structure of the blood vessels in the retina has been used for biometric identification.

Sensory Layer: Retina

- Delicate two-layered membrane
  - Pigmented layer
    - Outer layer
    - Absorbs light and prevents its scattering
    - Stores vitamin A

Sensory Layer: Retina

- Neural layer
  - Photoreceptor: transduce light energy
  - Cells that transmit and process signals: bipolar cells, ganglion cells, amacrine cells, and horizontal cells

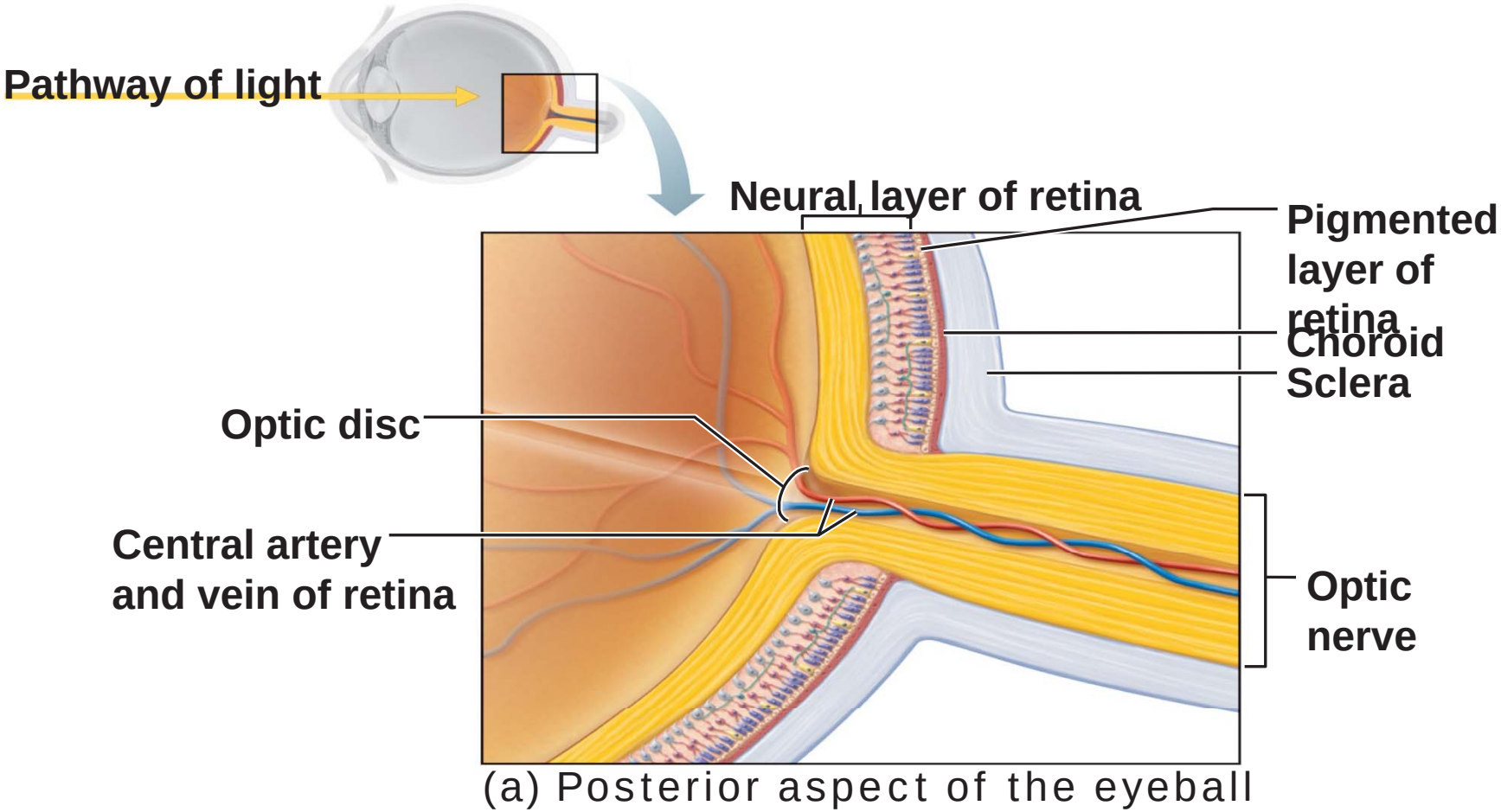

Pathway of light
Neural layer of retina
Pigmented layer of retina
Choroid
Sclera
Optic disc
Central artery and vein of retina
Optic nerve
(a) Posterior aspect of the eyeball

Figure 15.6a

The Retina

- Ganglion cell axons
  - Run along the inner surface of the retina
  - Leave the eye as the optic nerve
- Optic disc (blind spot)
  - Site where the optic nerve leaves the eye
  - Lacks photoreceptors

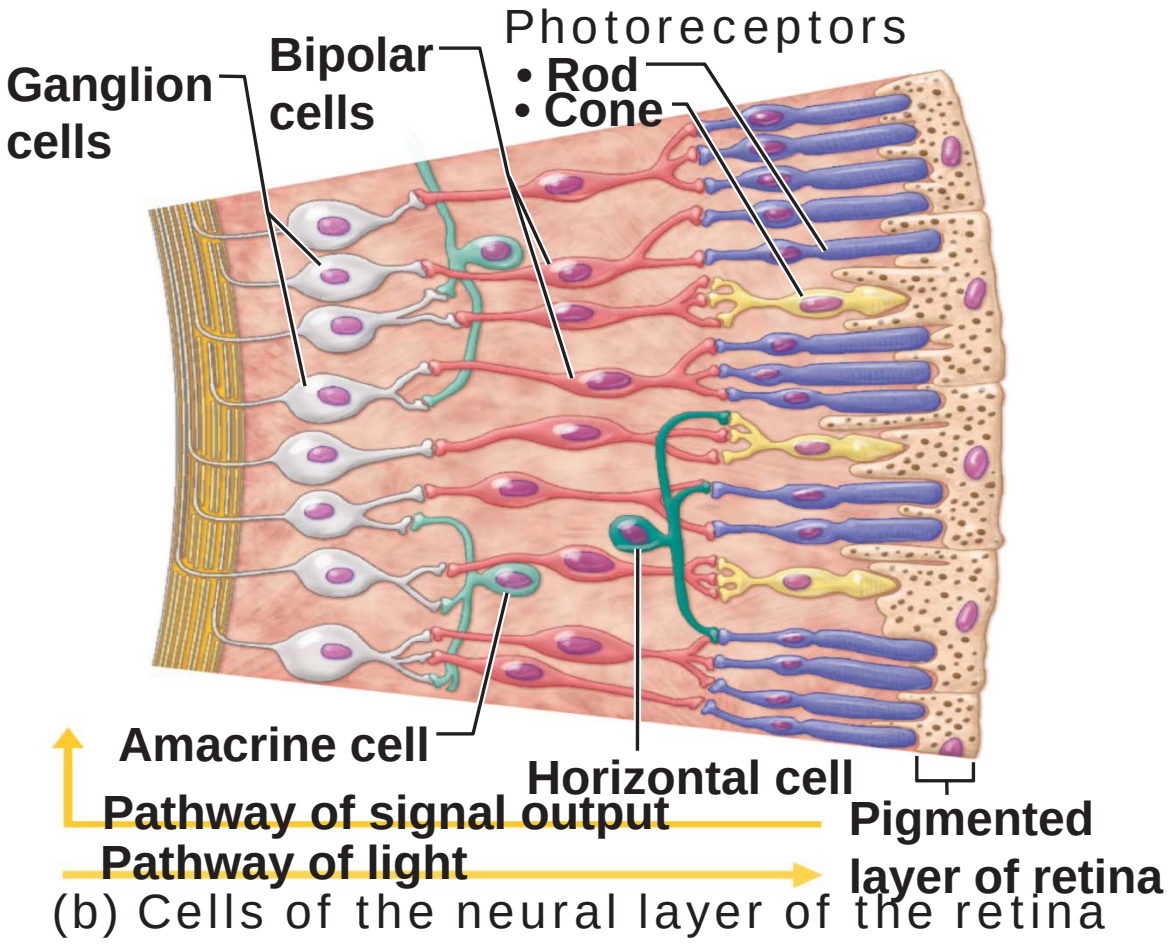
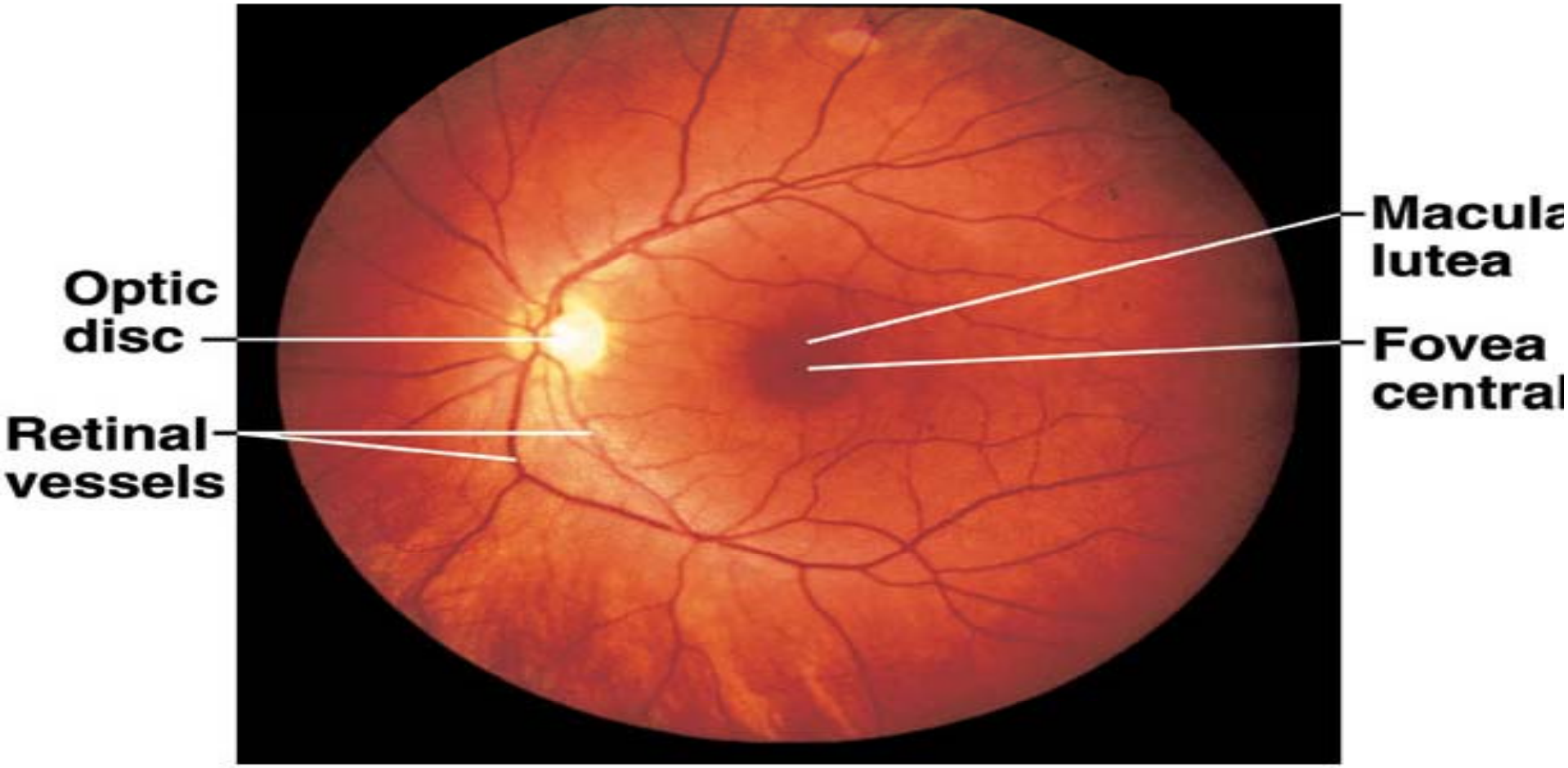
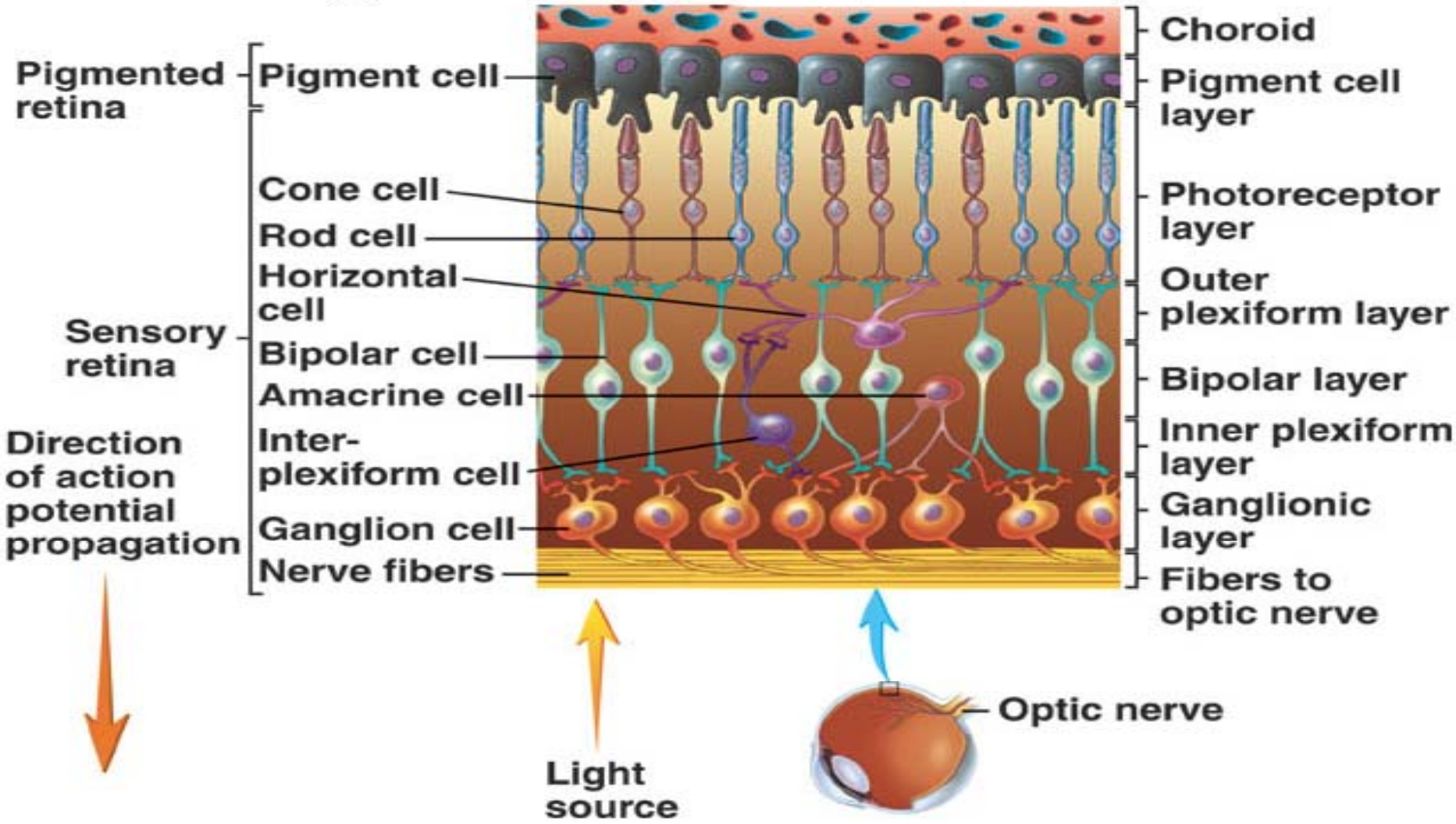

Photoreceptors
• Rod
• Cone
Ganglion cells
Bipolar cells
Amacrine cell
Horizontal cell
Pathway of signal output
Pathway of light
Pigmented layer of retina
(b) Cells of the neural layer of the retina

Figure 15.6b

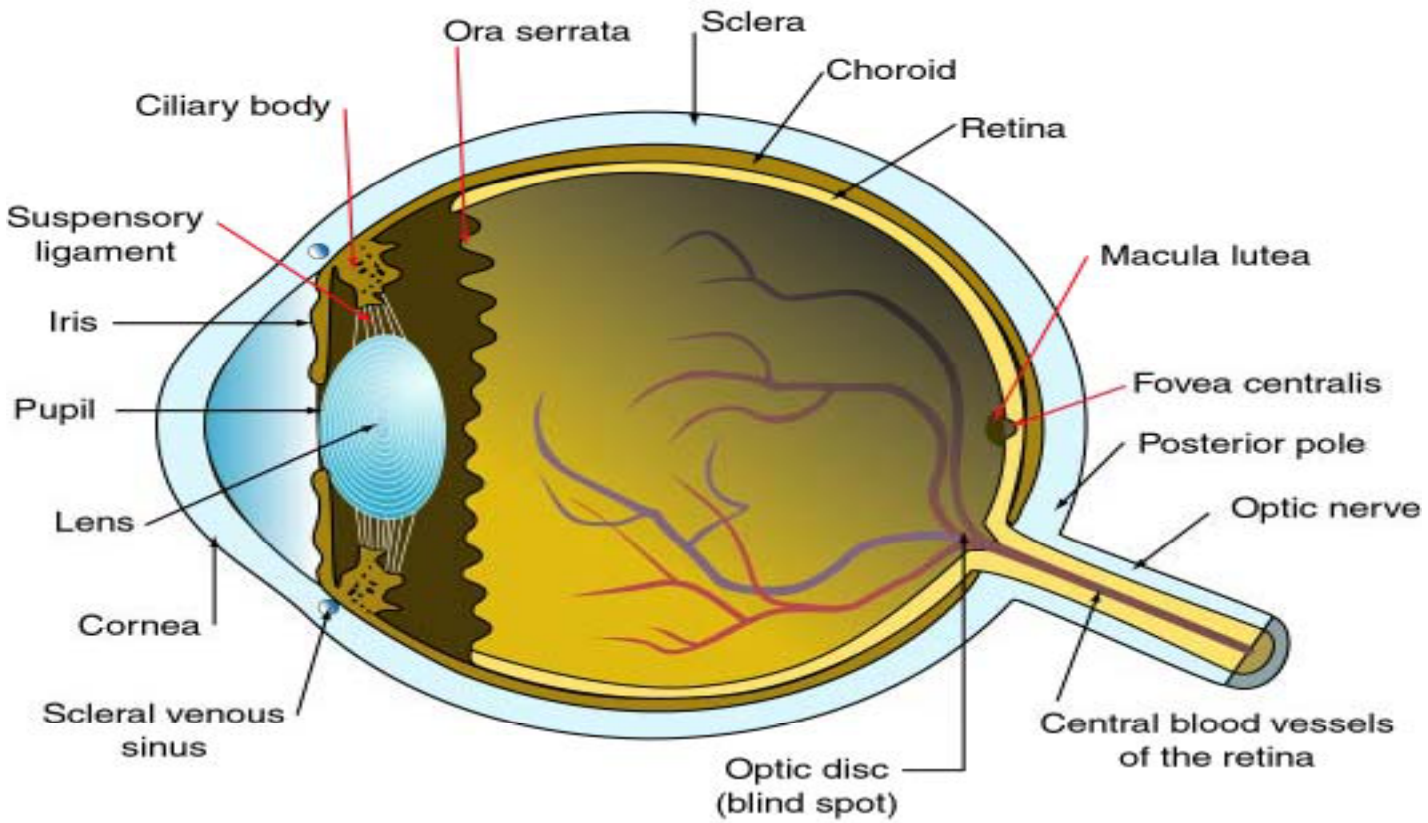
Photoreceptors

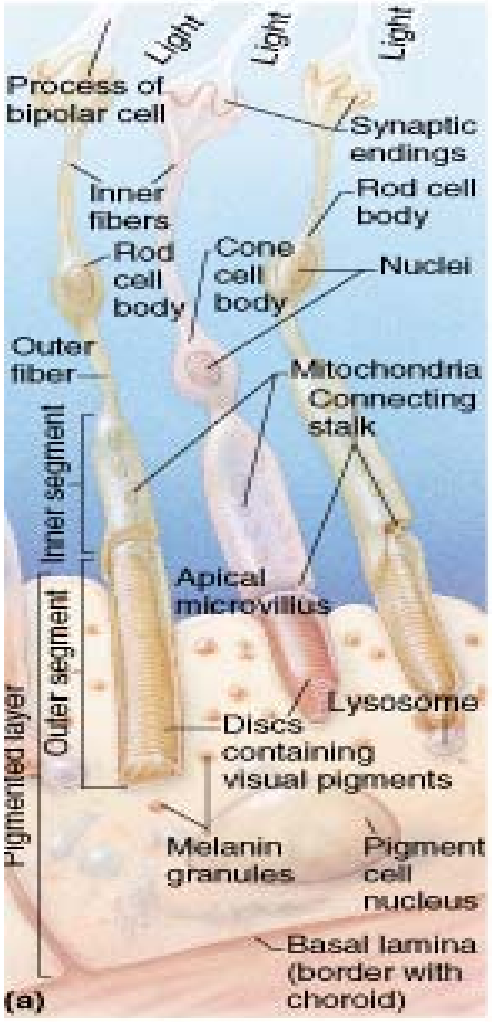
- Rods
- Cones
- Macula
- Fovea centralis


Optic disc
Retinal vessels
Macula lutea
Fovea central



Internal Structures of the Eye (saggital section)




Light
Light
Light
Process of bipolar cell
Synaptic endings
Inner fibers
Rod cell body
Rod cell body
Cone cell body
Nuclei
Outer fiber
Mitochondria
Connecting stalk
Inner segment
Apical microvillus
Outer segment
Lysosome
Discs containing visual pigments
Pigmented layer
Melanin granules
Pigment cell nucleus
Basal lamina (border with choroid)
(a)

- Optic Nerve
- Optic disc
- Blind Spot

Photoreceptors

- Rods
  - More numerous at peripheral region of retina, away from the macula lutea
  - Operate in dim light
  - Provide indistinct, fuzzy, non color peripheral vision

Photoreceptors

- Cones
  - Found in the macula lutea; concentrated in the fovea centralis
  - Operate in bright light
  - Provide high-acuity color vision

Blood Supply to the Retina

- Two sources of blood supply
  - Choroid supplies the outer third (photoreceptors)
  - Central artery and vein of the retina supply the inner two-thirds

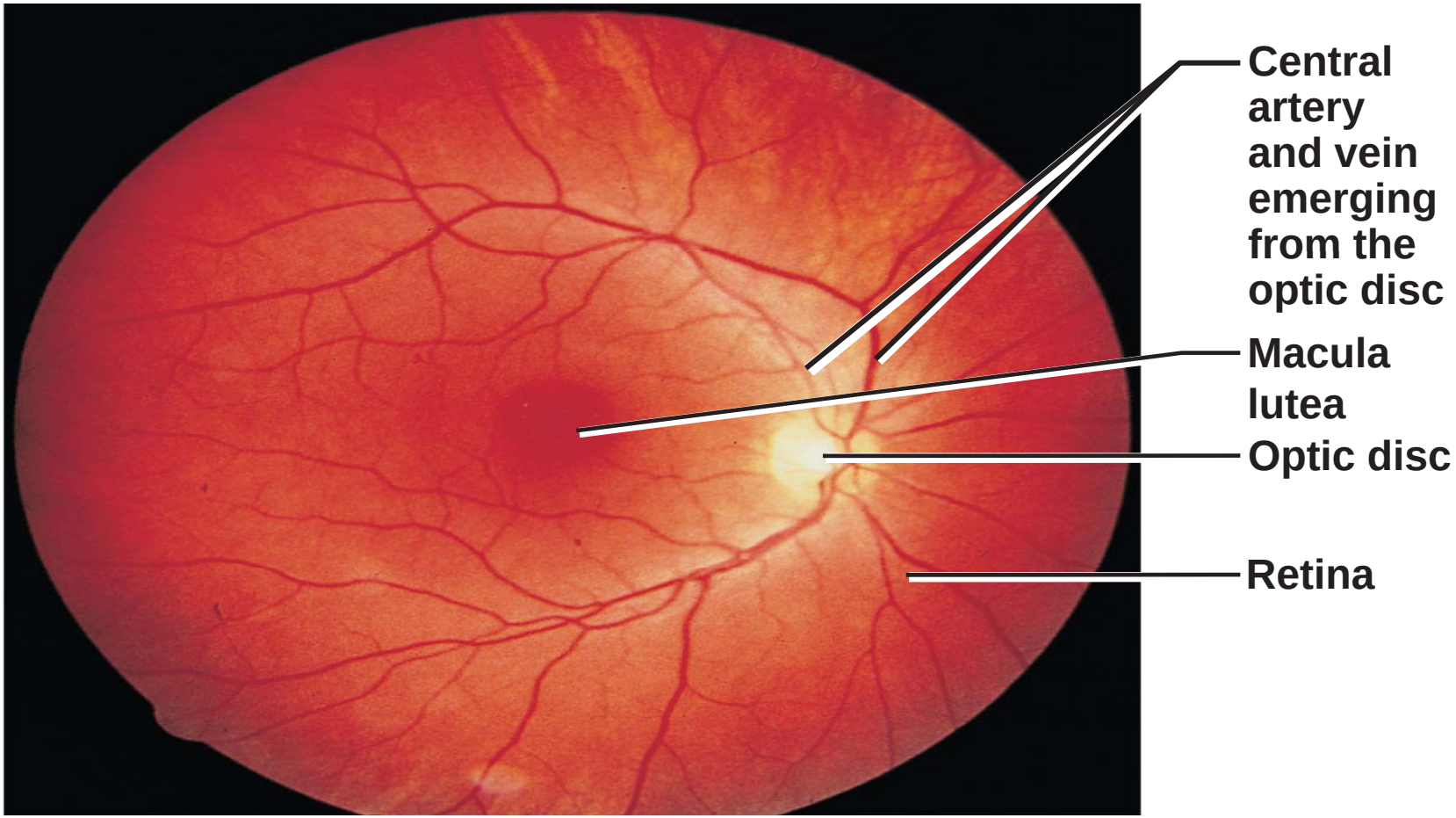
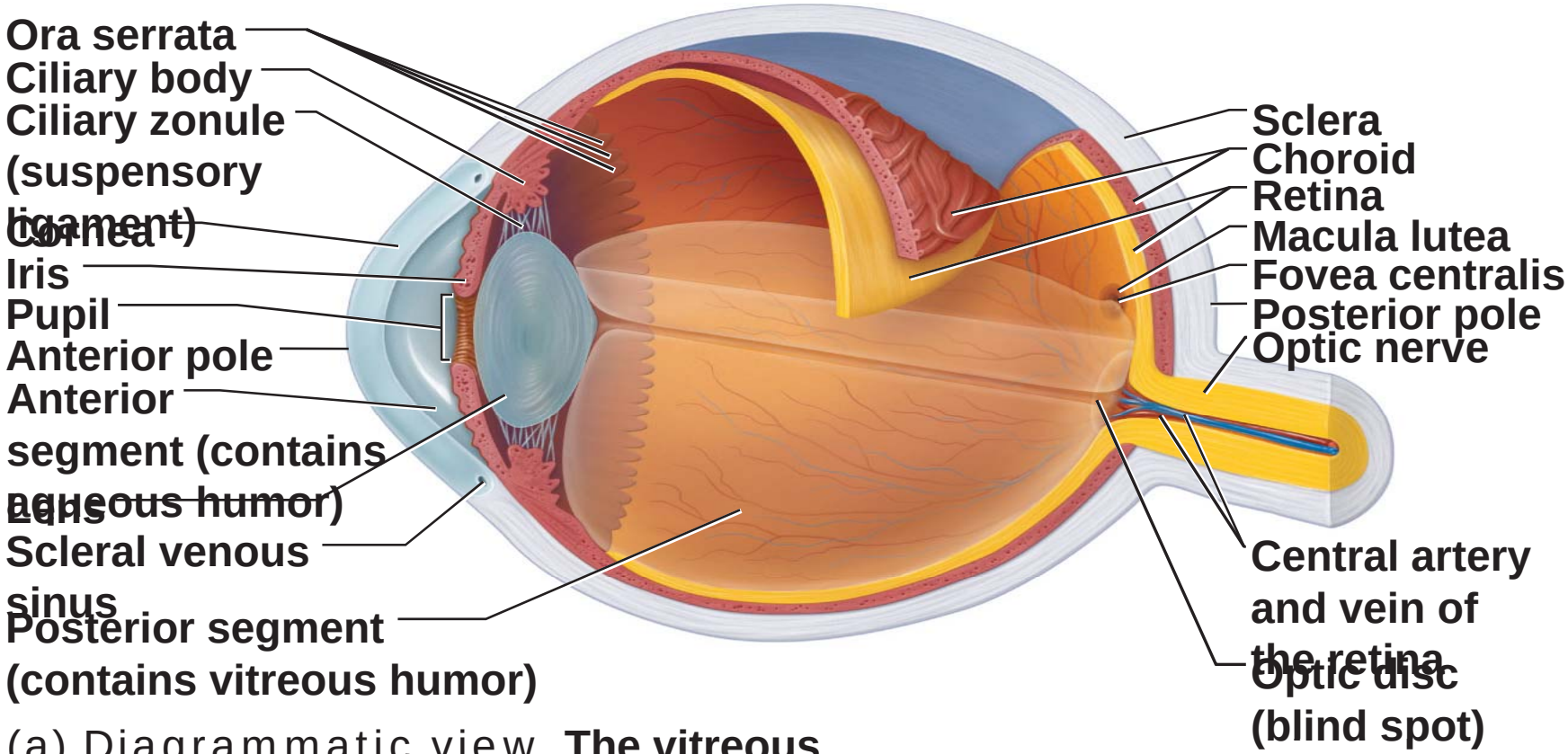

Central artery and vein emerging from the optic disc
Macula lutea
Optic disc
Retina

Figure 15.7

Internal Chambers and Fluids

- The lens and ciliary zonule separate the anterior and posterior segments



(a) Diagrammatic view. **The vitreous humor is illustrated only in the bottom part of the eyeball.**

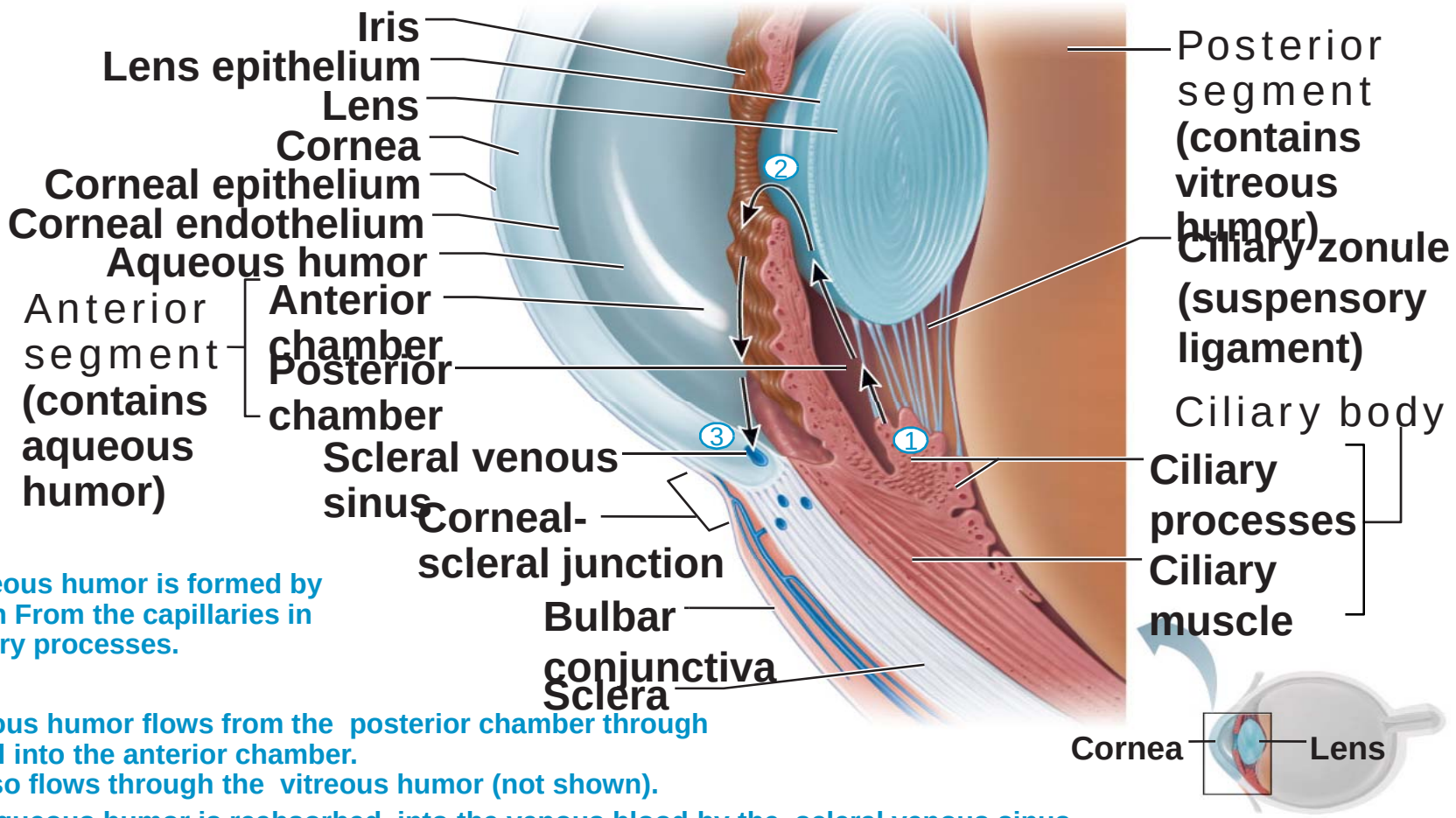
Figure 15.4a

Internal Chambers and Fluids

- Posterior segment contains vitreous humor that:
  - Transmits light
  - Supports the posterior surface of the lens
  - Holds the neural retina firmly against the pigmented layer
  - Contributes to intraocular pressure
- Anterior segment is composed of two chambers
  - Anterior chamber—between the cornea and the iris
  - Posterior chamber—between the iris and the lens

Internal Chambers and Fluids

- Anterior segment contains aqueous humor
  - Plasma like fluid continuously filtered from capillaries of the ciliary processes
  - Drains via the scleral venous sinus (canal of Schlemm) at the sclera-cornea junction
  - Supplies nutrients and oxygen mainly to the lens and cornea but also to the retina, and removes wastes
- Glaucoma: compression of the retina and optic nerve if drainage of aqueous humor is blocked



1 Aqueous humor is formed by filtration From the capillaries in the ciliary processes.

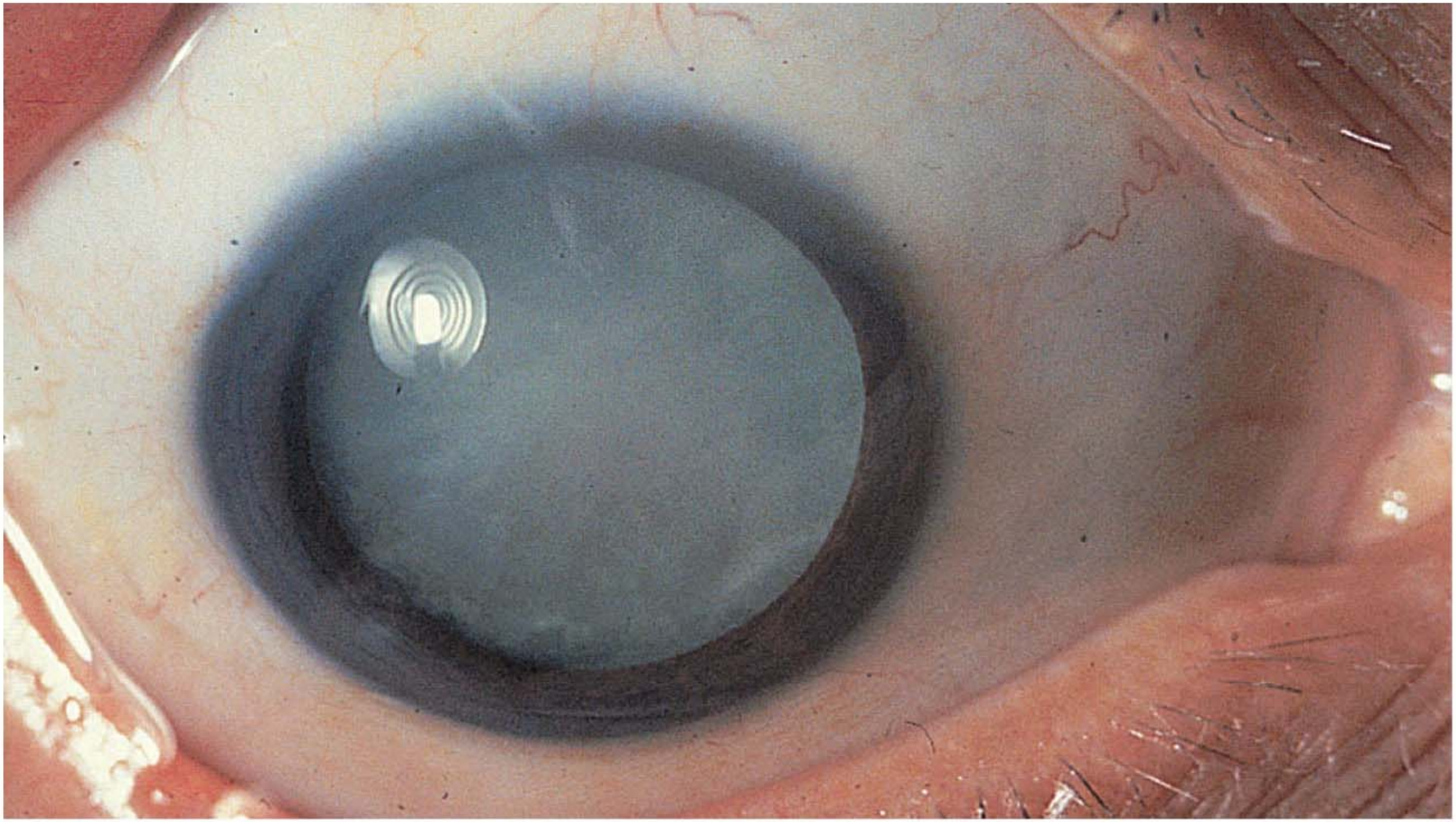
2 Aqueous humor flows from the posterior chamber through the pupil into the anterior chamber.
Some also flows through the vitreous humor (not shown).

3 Aqueous humor is reabsorbed into the venous blood by the scleral venous sinus.

Figure 15.8

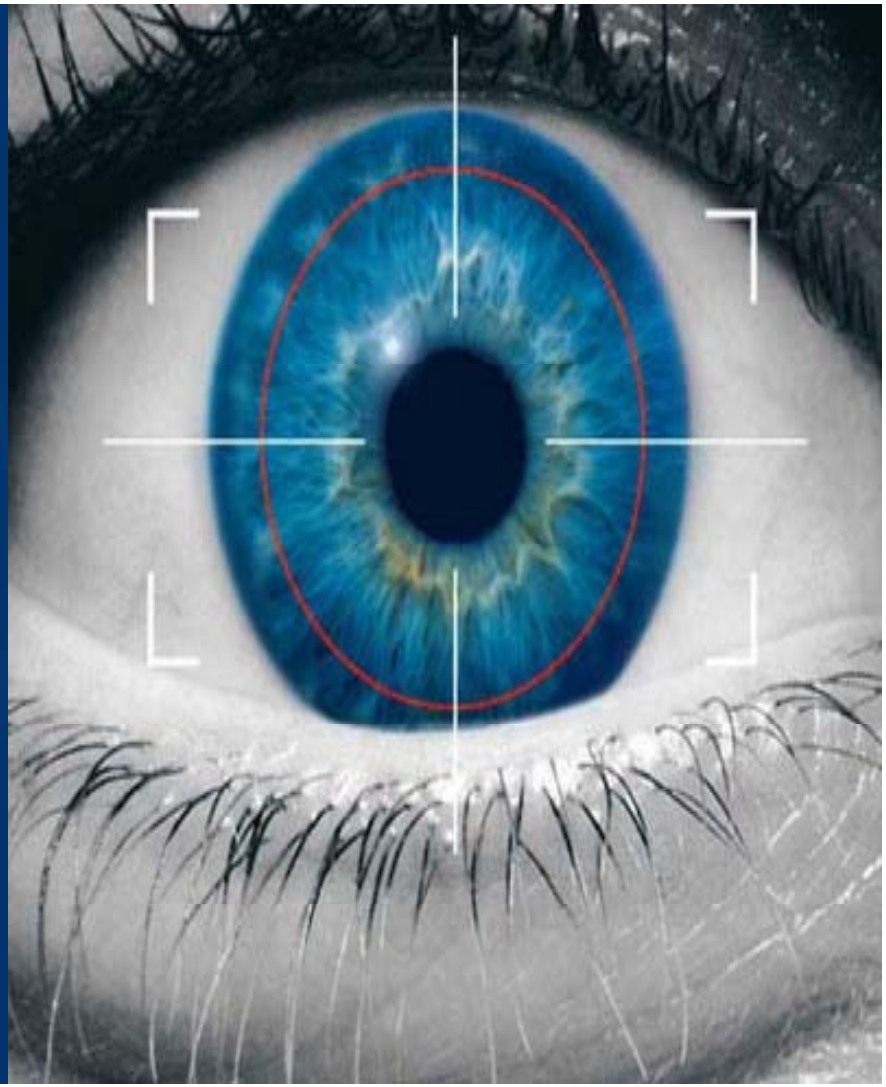
Lens

- Biconvex, transparent, flexible, elastic, and avascular
- Allows precise focusing of light on the retina
- Cells of lens epithelium differentiate into lens fibers that form the bulk of the lens
- Lens fibers—cells filled with the transparent protein crystallin
- Lens becomes denser, more convex, and less elastic with age
- Cataracts (clouding of lens) occur as a consequence of aging, diabetes mellitus, heavy smoking, and frequent exposure to intense sunlight

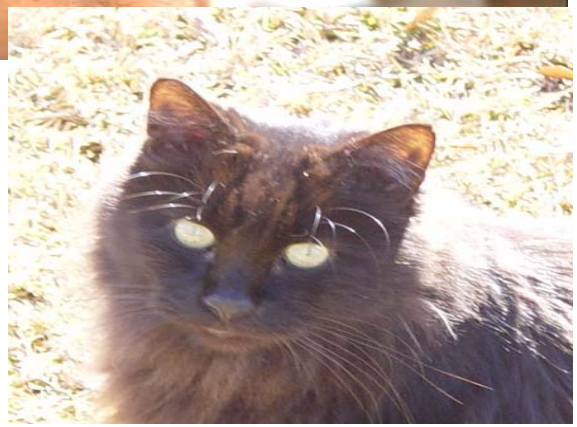


The Iris

- Visible colored part of the eye
- Attached to the ciliary body
- Composed of smooth muscle
- Pupil – the round, central opening
  - Sphincter pupillae muscle (constrictor or circular)
  - Dilator pupillae muscle (dilator or radial)
    - Act to vary the size of the pupil



Pupillary dilation and constriction



Light

- Our eyes respond to visible light, a small portion of the electromagnetic spectrum
- Light: packets of energy called photons (quanta) that travel in a wavelike fashion
- Rods and cones respond to different wavelengths of the visible spectrum

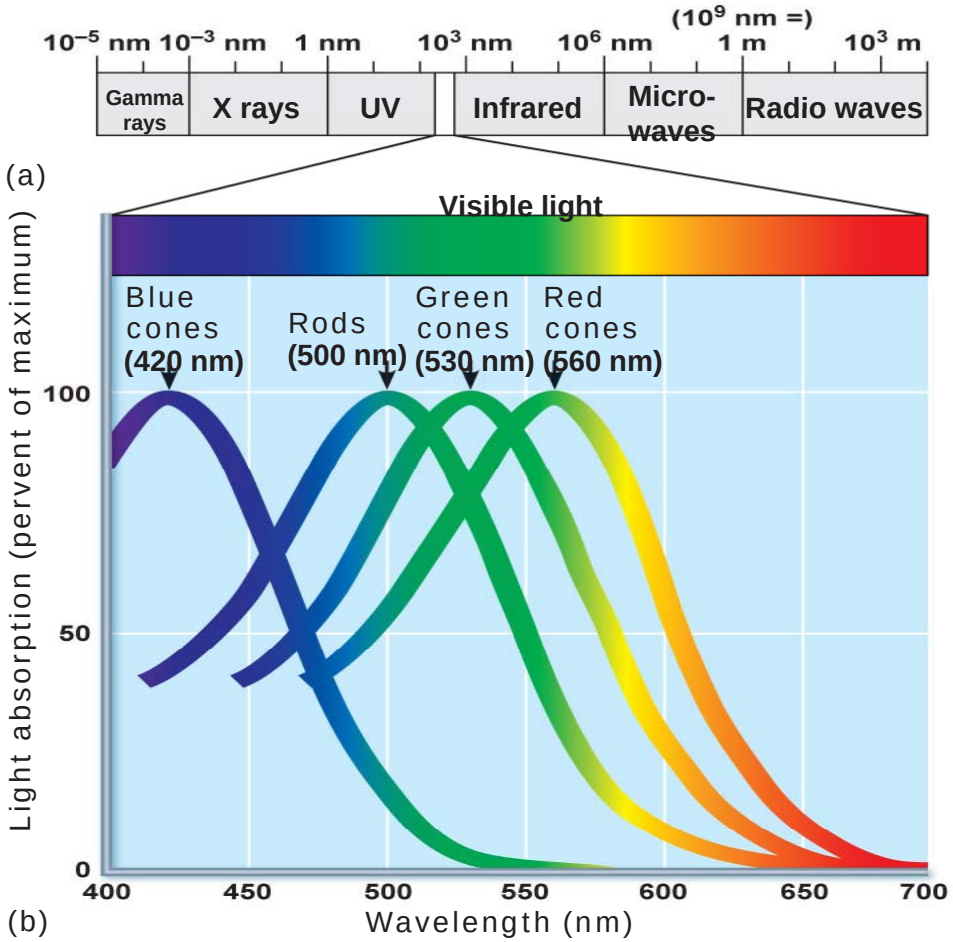

10^{-5} nm
10^{-3} nm
1 nm
10^{3} nm
10^{6} nm
(10^{9} nm =) 1 m
10^{3} m
Gamma rays
X rays
UV
Infrared
Micro-waves
Radio waves
(a)
Visible light
Blue cones (420 nm)
Rods (500 nm)
Green cones (530 nm)
Red cones (560 nm)
Light absorption (pervent of maximum)
100
50
0
400
450
500
550
600
650
700
Wavelength (nm)
(b)

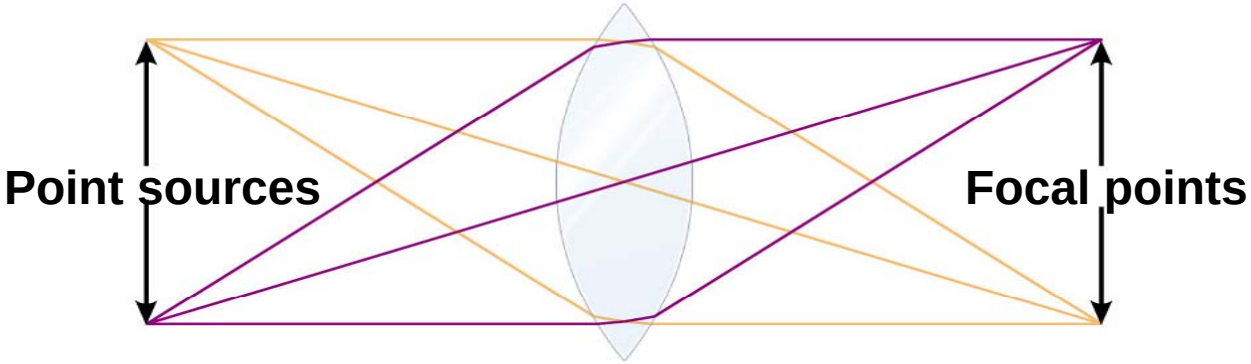
Figure 15.10

Refraction and Lenses

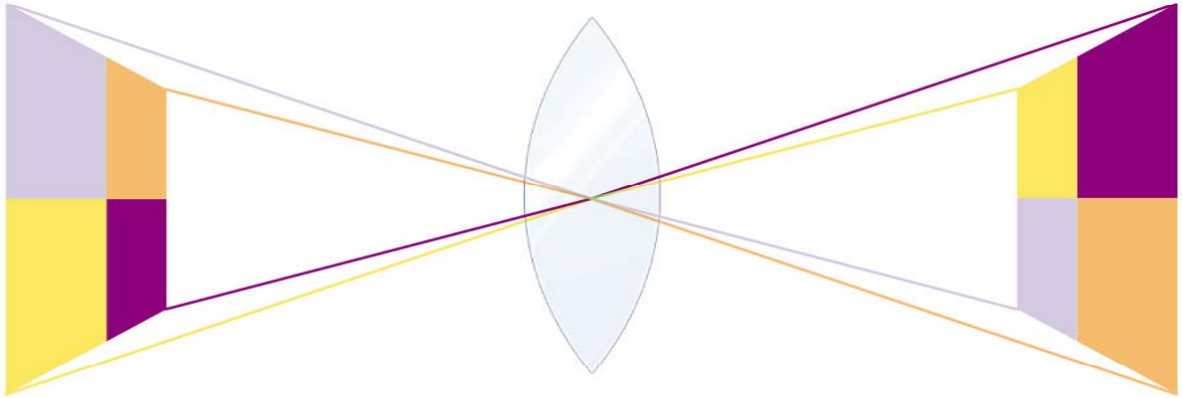
- Refraction
  - Bending of a light ray due to change in speed when light passes from one transparent medium to another
  - Occurs when light meets the surface of a different medium at an oblique angle

Refraction and Lenses

- Light passing through a convex lens (as in the eye) is bent so that the rays converge at a focal point
- The image formed at the focal point is upside-down and reversed right to left



(a) Focusing of two points of light.



(b) The image is inverted—upside down and reversed.

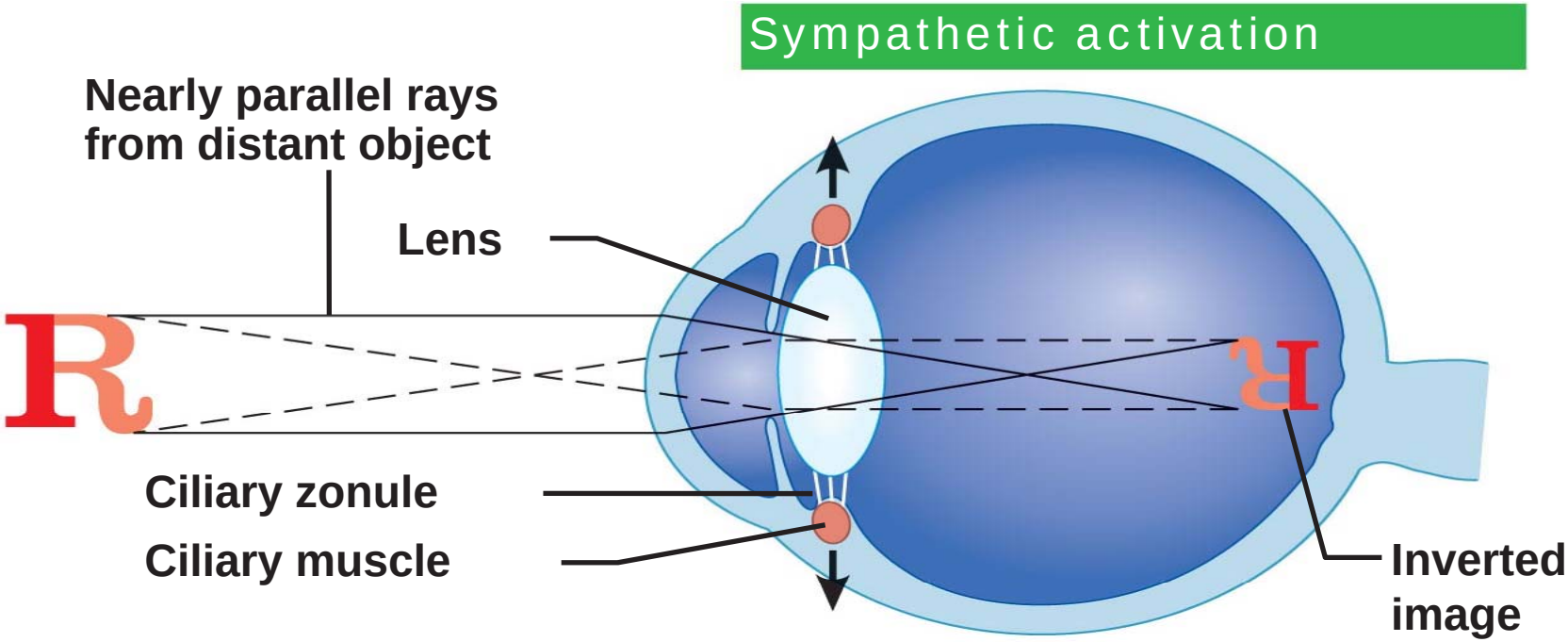
Figure 15.12

Focusing Light on the Retina

- Pathway of light entering the eye: cornea, aqueous humor, lens, vitreous humor, neural layer of retina, photoreceptors
- Light is refracted
  - At the cornea
  - Entering the lens
  - Leaving the lens
- Change in lens curvature allows for fine focusing of an image

Focusing for Distant Vision

- Light rays from distant objects are nearly parallel at the eye and need little refraction beyond what occurs in the at-rest eye
- Far point of vision: the distance beyond which no change in lens shape is needed for focusing; 20 feet for emmetropic (normal) eye
- Ciliary muscles are relaxed
- Lens is stretched flat by tension in the ciliary zonule



(a) Lens is flattened for distant vision. **Sympathetic input relaxes the ciliary muscle, tightening the ciliary zonule, and flattening the lens.**

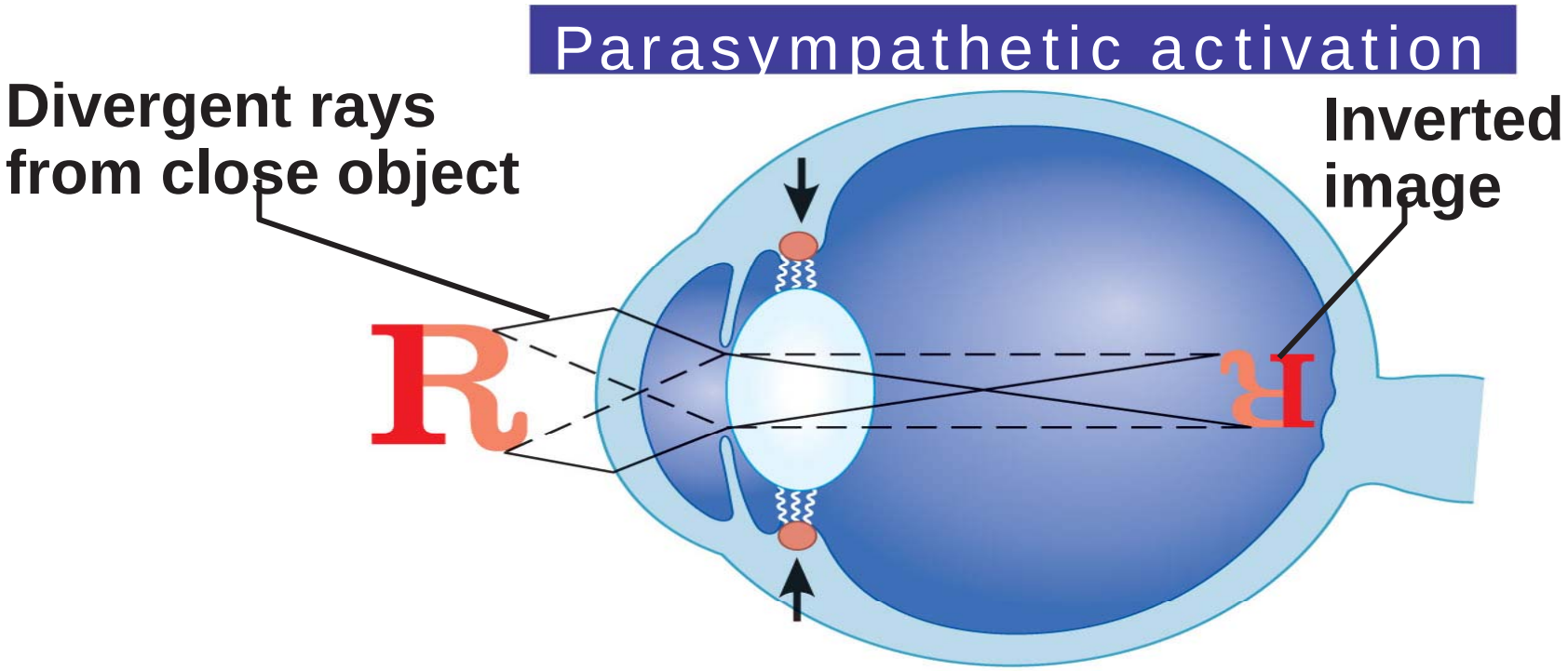
Figure 15.13a

Focusing for Close Vision

- Light from a close object diverges as it approaches the eye; requires that the eye make active adjustments

Focusing for Close Vision

- Close vision requires
  - Accommodation—changing the lens shape by ciliary muscles to increase refractory power
    - Near point of vision is determined by the maximum bulge the lens can achieve
    - Presbyopia—loss of accommodation over age 50
  - Constriction—the accommodation pupillary reflex constricts the pupils to prevent the most divergent light rays from entering the eye
  - Convergence—medial rotation of the eyeballs toward the object being viewed



(b) Lens bulges for close vision. **Parasympathetic input contracts the ciliary muscle, loosening the ciliary zonule, allowing the lens to bulge.**

Figure 15.13b

Problems of Refraction

- Myopia (nearsightedness)—focal point is in front of the retina, e.g. in a longer than normal eyeball
  - Corrected with a concave lens
- Hyperopia (farsightedness)—focal point is behind the retina, e.g. in a shorter than normal eyeball
  - Corrected with a convex lens
- Astigmatism—caused by unequal curvatures in different parts of the cornea or lens
  - Corrected with cylindrically ground lenses, corneal implants, or laser procedures

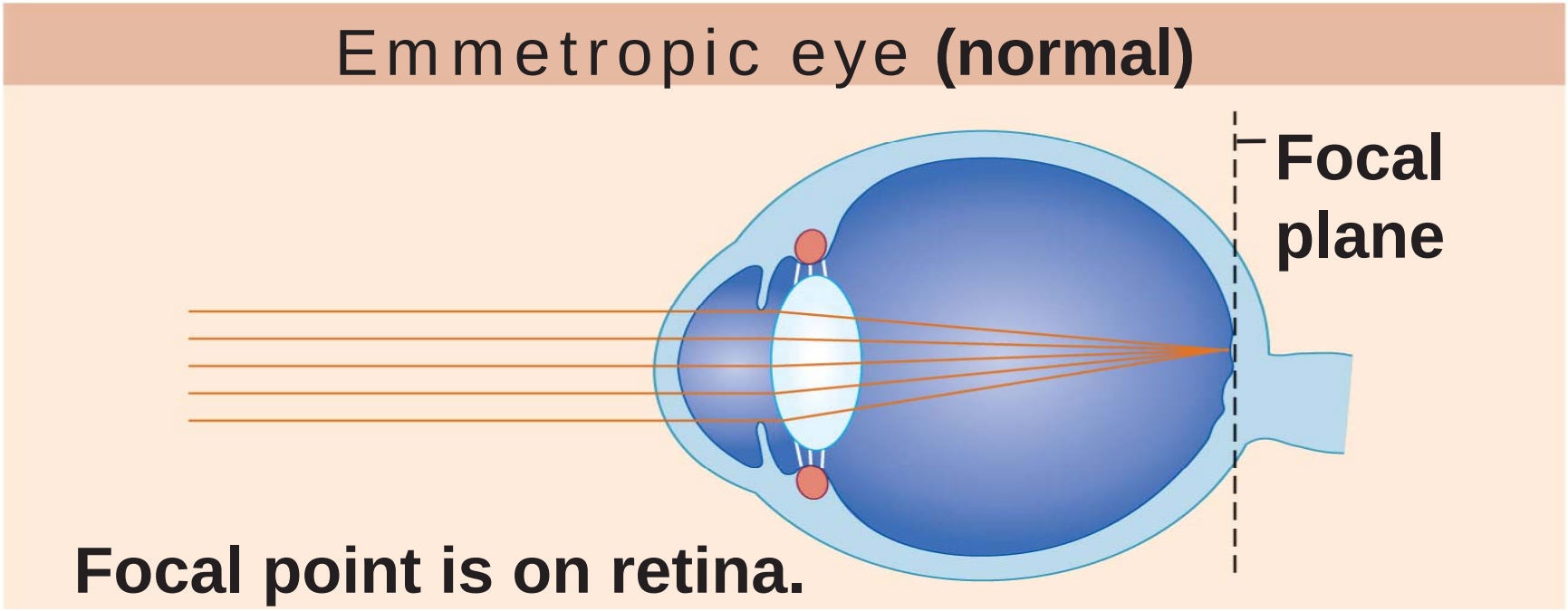


Figure 15.14 (1 of 3)

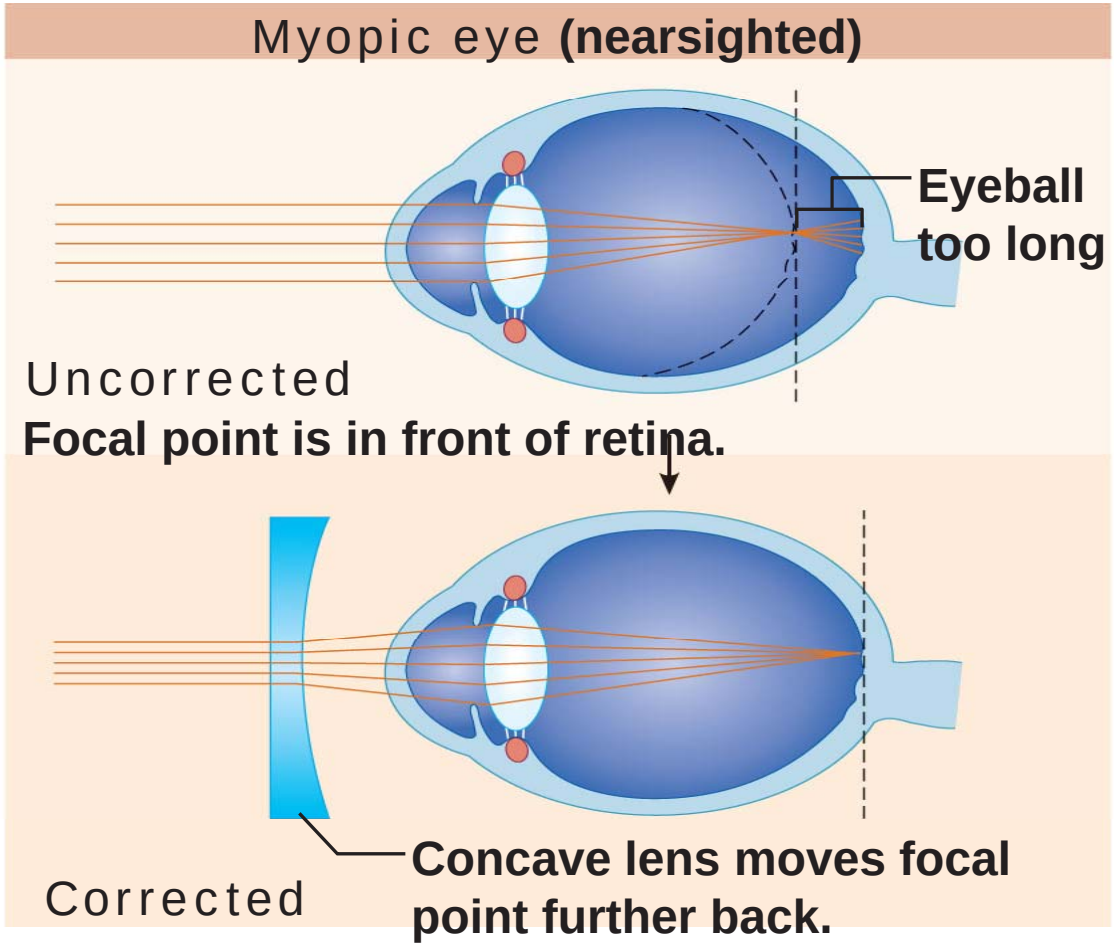


Figure 15.14 (2 of 3)

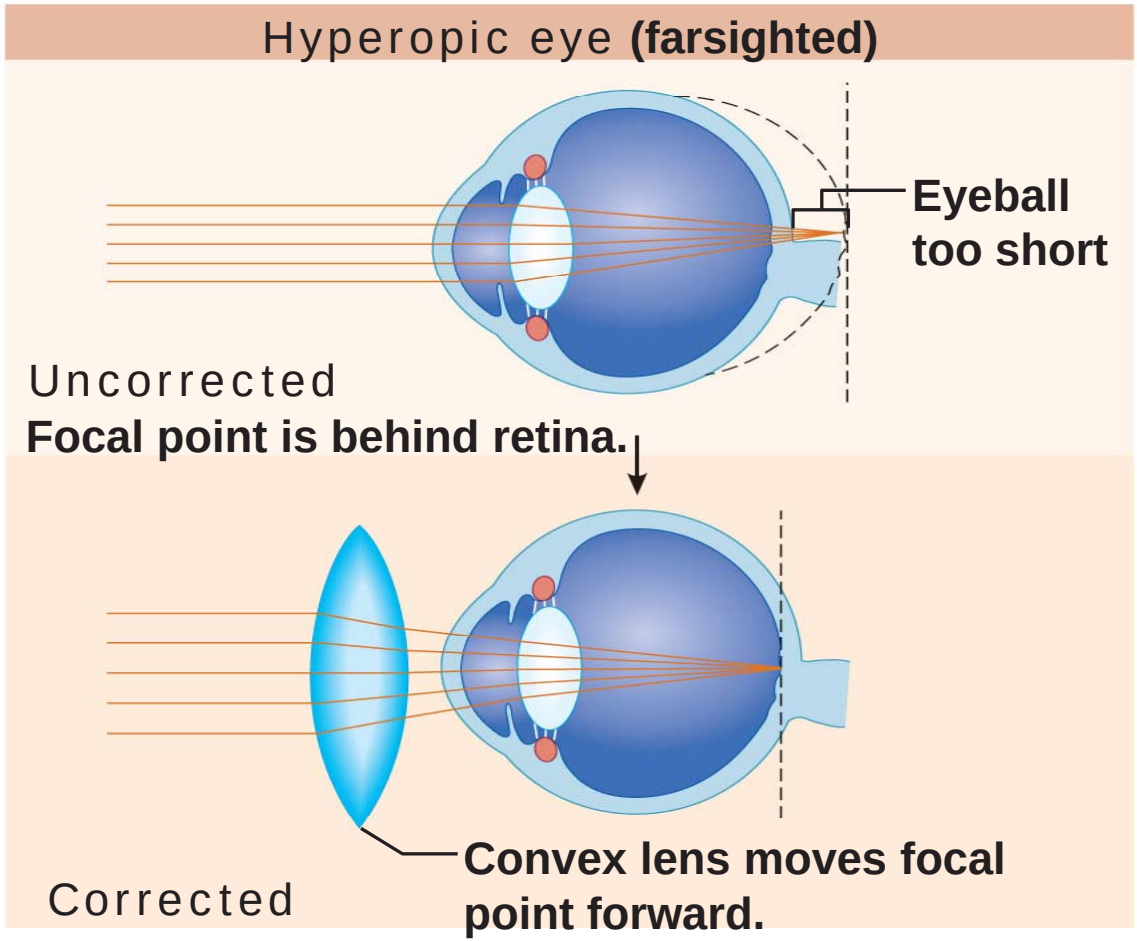
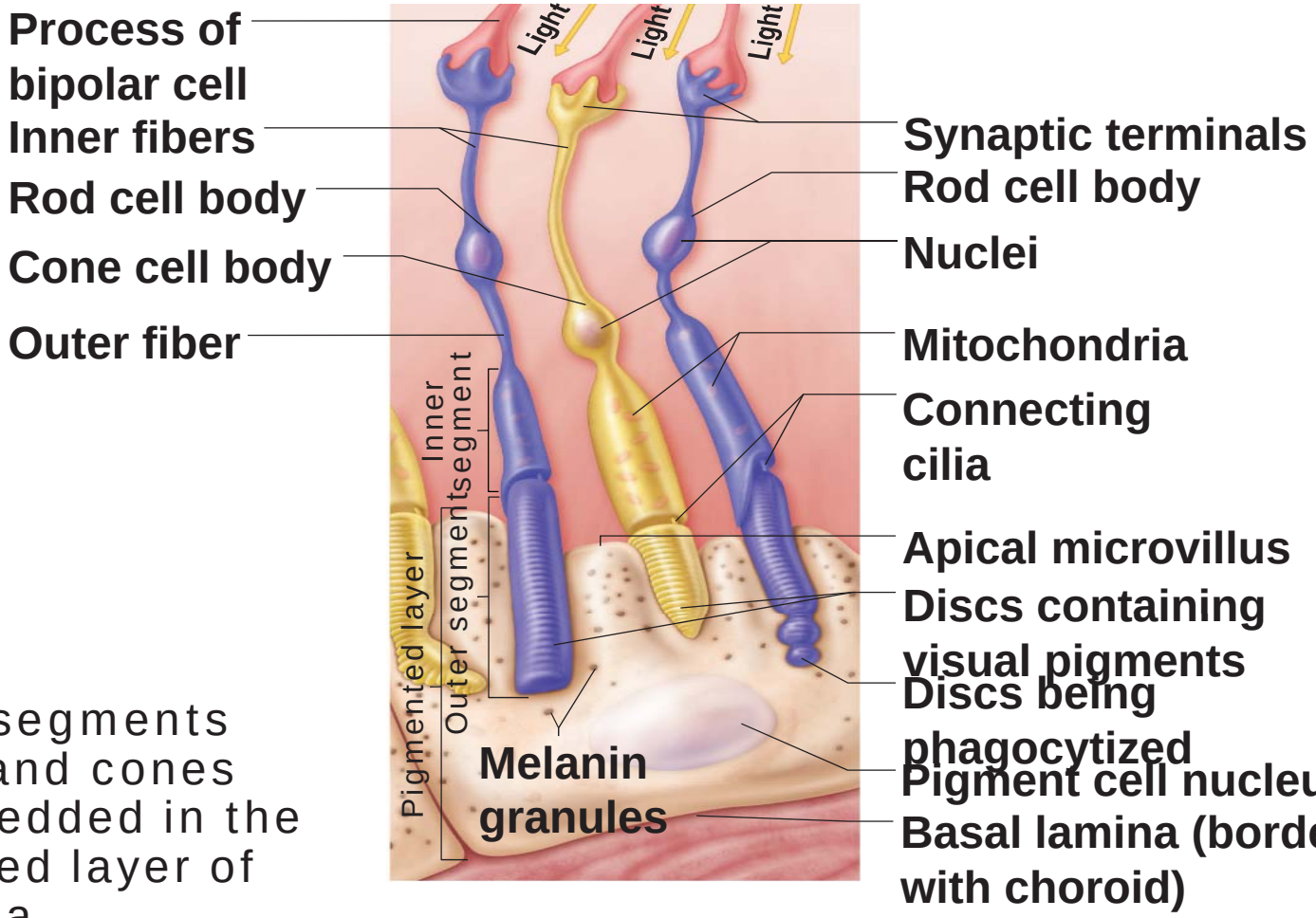


Figure 15.14 (3 of 3)

Functional Anatomy of Photoreceptors

- Rods and cones
  - Outer segment of each contains visual pigments (photopigments)—molecules that change shape as they absorb light
  - Inner segment of each joins the cell body



The outer segments of rods and cones are embedded in the pigmented layer of the retina.

Figure 15.15a

Rods

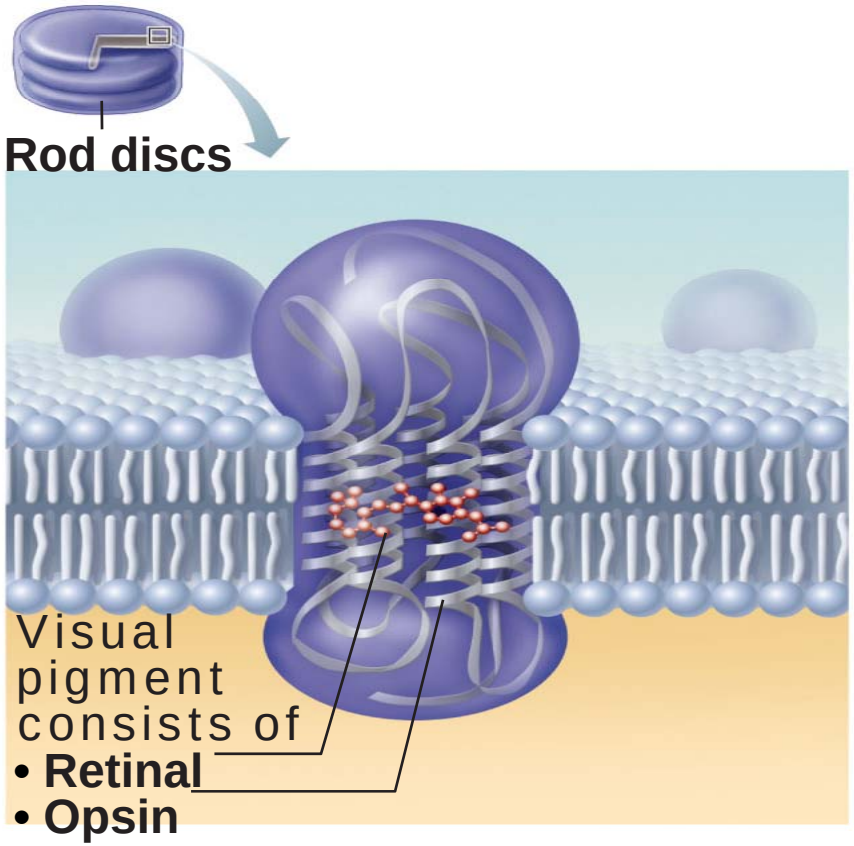
- Functional characteristics
  - Very sensitive to dim light
  - Best suited for night vision and peripheral vision
  - Perceived input is in gray tones only
  - Pathways converge, resulting in fuzzy and indistinct images

Cones

- Functional characteristics
  - Need bright light for activation (have low sensitivity)
  - Have one of three pigments that furnish a vividly colored view
  - Nonconverging pathways result in detailed, high-resolution vision

Chemistry of Visual Pigments

- Retinal
  - Light-absorbing molecule that combines with one of four proteins (opsin) to form visual pigments
  - Synthesized from vitamin A
  - Two isomers: 11-*cis*-retinal (bent form) and all-*trans*-retinal (straight form)
- Conversion of 11-*cis*-retinal to all-*trans*-retinal initiates a chain of reactions leading to transmission of electrical impulses in the optic nerve

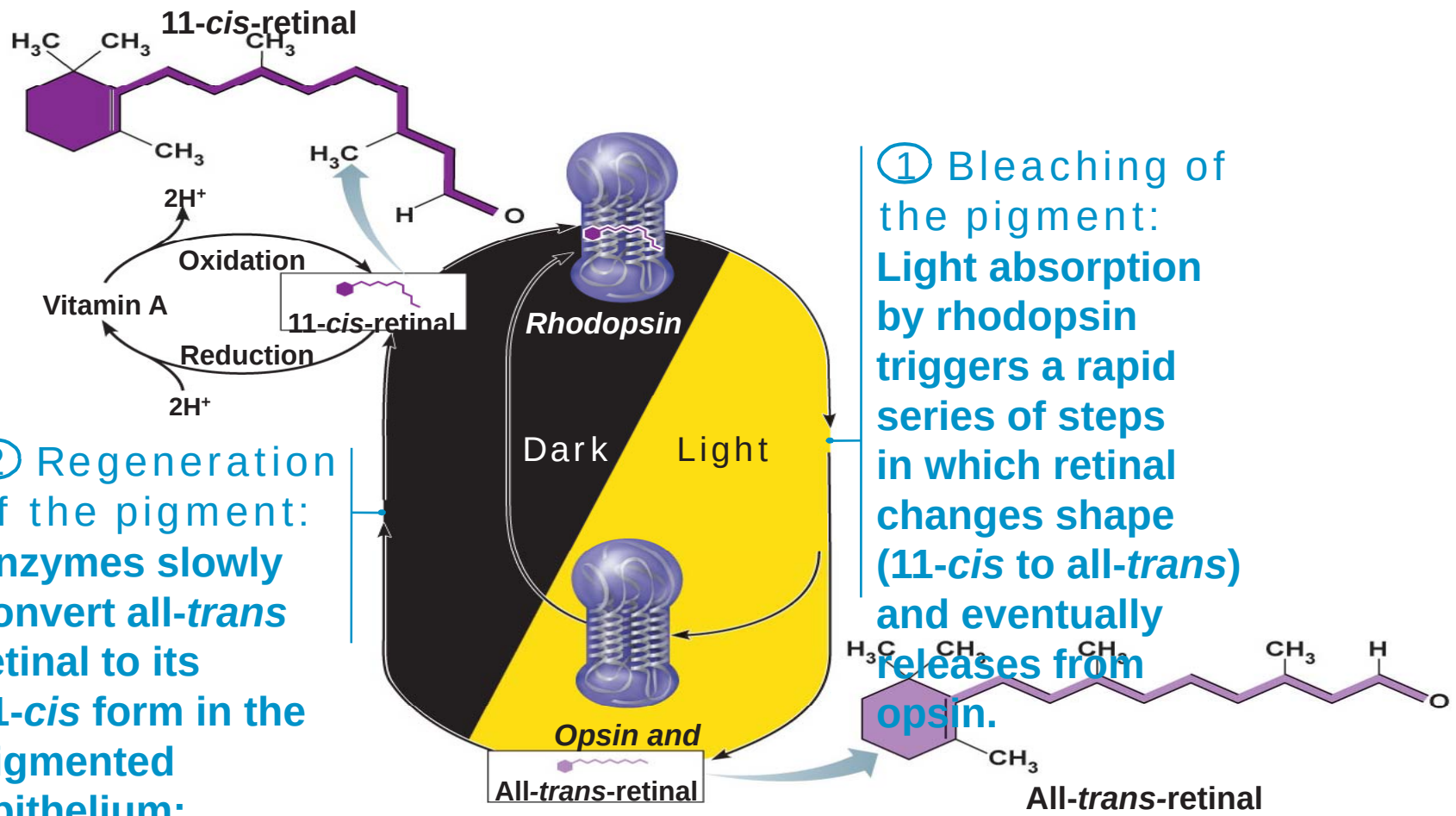


(b) Rhodopsin, the visual pigment in rods, is embedded in the membrane that forms discs in the outer segment.

Figure 15.15b

Excitation of Rods

- The visual pigment of rods is rhodopsin (opsin + 11-*cis*-retinal)
- In the dark, rhodopsin forms and accumulates
  - Regenerated from all-*trans*-retinal
  - Formed from vitamin A
- When light is absorbed, rhodopsin breaks down
- 11-*cis* isomer is converted into the all-*trans* isomer
- Retinal and opsin separate (bleaching of the pigment)



① Bleaching of the pigment: **Light absorption by rhodopsin triggers a rapid series of steps in which retinal changes shape (11-*cis* to all-*trans*) and eventually releases from opsin.**

② Regeneration of the pigment: **Enzymes slowly convert all-*trans* retinal to its 11-*cis* form in the pigmented epithelium; requires ATP**

Figure 15.16

Excitation of Cones

- Method of excitation is similar to that of rods
- There are three types of cones, named for the colors of light absorbed: blue, green, and red
- Intermediate hues are perceived by activation of more than one type of cone at the same time
- Color blindness is due to a congenital lack of one or more of the cone types

Phototransduction

- In the dark, cGMP binds to and opens cation channels in the outer segments of photoreceptor cells
  - Na^+ and Ca^{2+} influx creates a depolarizing dark potential of about –40 mV

Phototransduction

- In the light, light-activated rhodopsin activates a G protein, transducin
  - Transducin activates phosphodiesterase (PDE)
  - PDE hydrolyzes cGMP to GMP and releases it from sodium channels
  - Without bound cGMP, sodium channels close; the membrane hyperpolarizes to about –70 mV

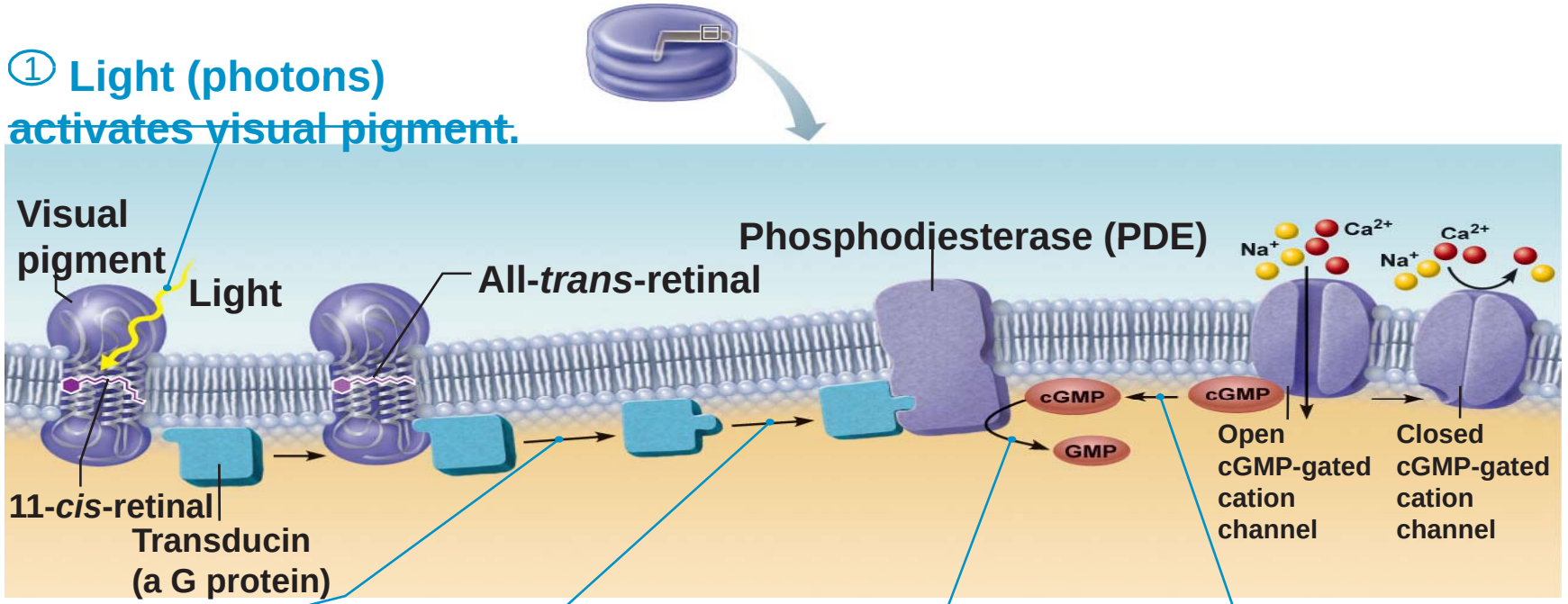

① Light (photons) activates visual pigment.
Visual pigment
Light
All-*trans*-retinal
Phosphodiesterase (PDE)
Ca^{2+}
Na^+
Ca^{2+}
Na^+
cGMP
cGMP
GMP
11-*cis*-retinal
Transducin (a G protein)
Open cGMP-gated cation channel
Closed cGMP-gated cation channel
② Visual pigment activates transducin (G protein).
③ Transducin activates phosphodiesterase (PDE).
④ PDE converts cGMP into GMP, causing cGMP levels to fall.
⑤ As cGMP levels fall, cGMP-gated cation channels close, resulting in hyperpolarization.

Figure 15.17

Signal Transmission in the Retina

- Photoreceptors and bipolar cells only generate graded potentials (EPSPs and IPSPs)
- Light hyperpolarizes photoreceptor cells, causing them to stop releasing the inhibitory neurotransmitter glutamate
- Bipolar cells (no longer inhibited) are then allowed to depolarize and release neurotransmitter onto ganglion cells
- Ganglion cells generate APs that are transmitted in the optic nerve

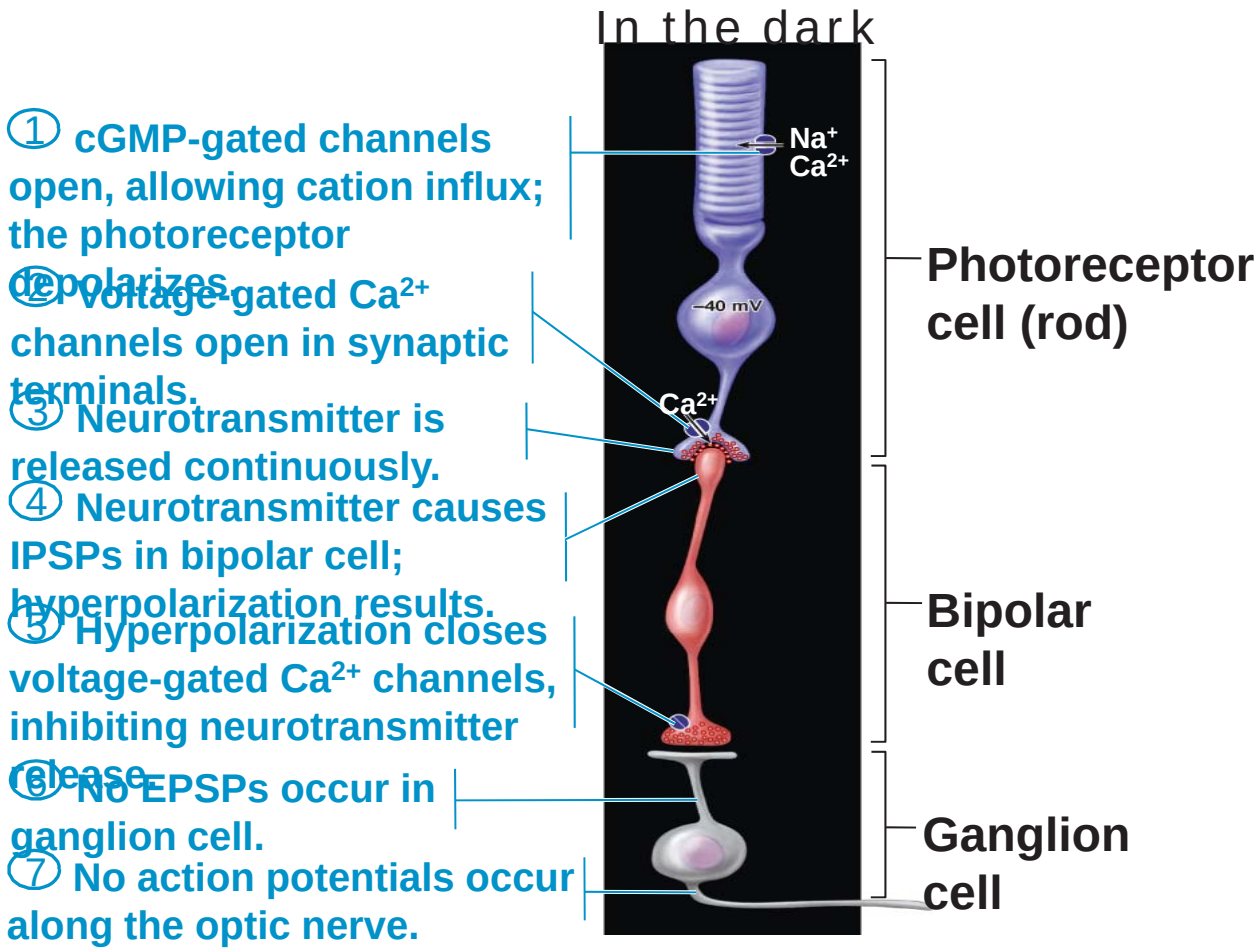


Figure 15.18 (1 of 2)

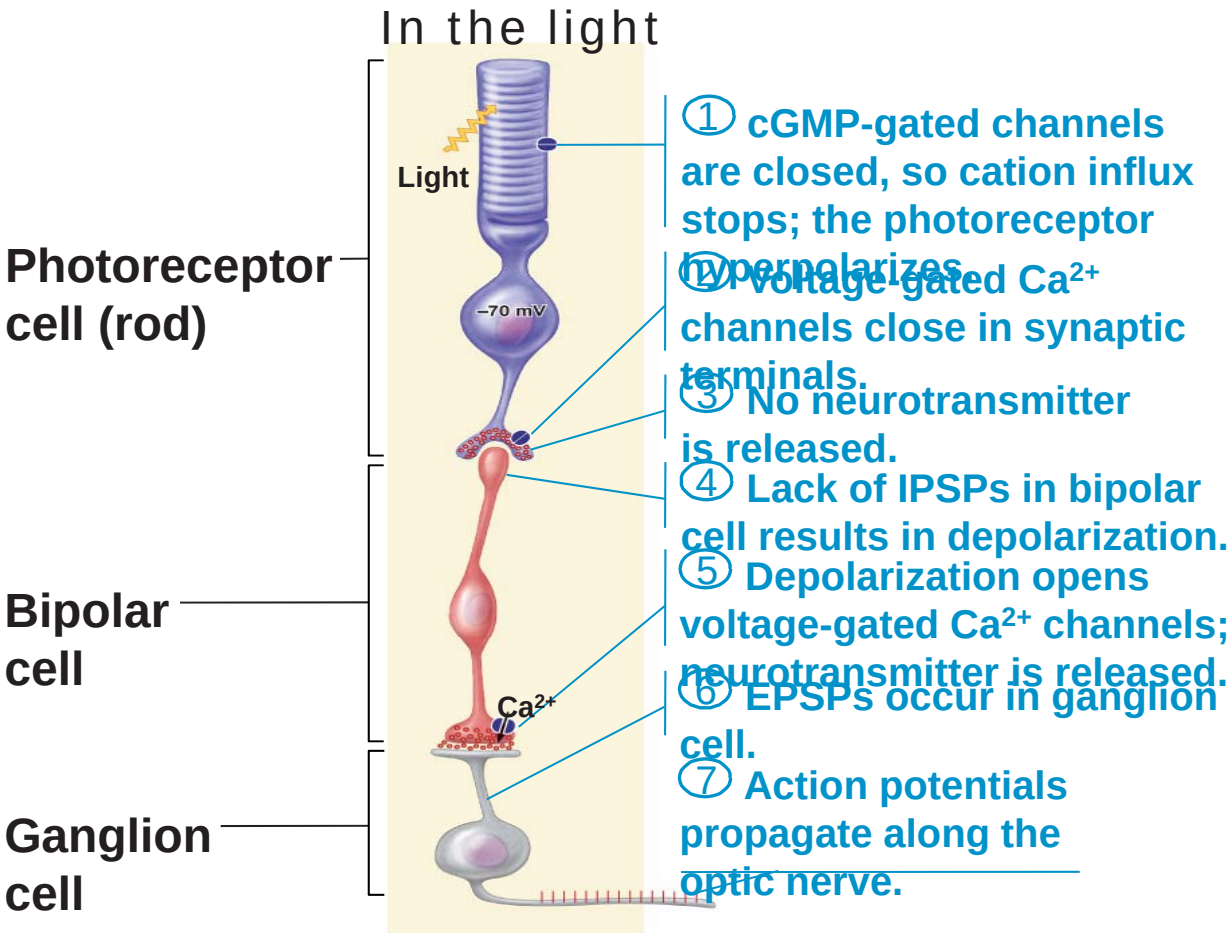


Figure 15.18 (2 of 2)

Light Adaptation

- Occurs when moving from darkness into bright light
  - Large amounts of pigments are broken down instantaneously, producing glare
  - Pupils constrict
  - Dramatic changes in retinal sensitivity: rod function ceases
  - Cones and neurons rapidly adapt
  - Visual acuity improves over 5–10 minutes

Dark Adaptation

- Occurs when moving from bright light into darkness
  - The reverse of light adaptation
  - Cones stop functioning in low-intensity light
  - Pupils dilate
  - Rhodopsin accumulates in the dark and retinal sensitivity increases within 20–30 minutes

Visual Pathway

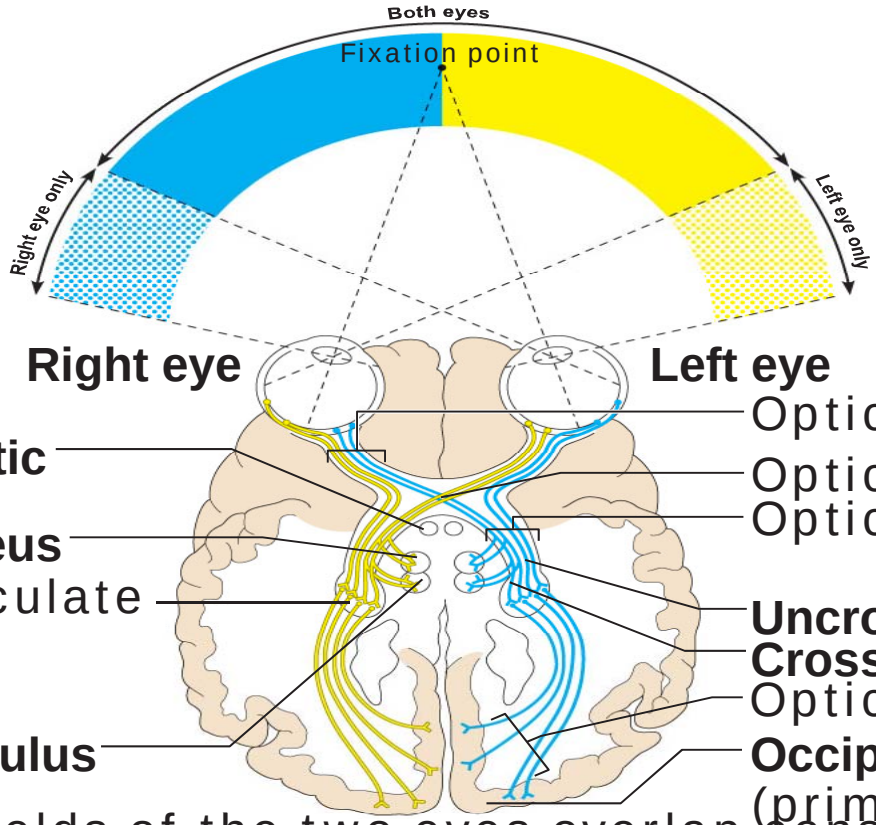
- Axons of retinal ganglion cells form the optic nerve
- Medial fibers of the optic nerve decussate at the optic chiasma
- Most fibers of the optic tracts continue to the lateral geniculate body of the thalamus

Visual Pathway

- The optic radiation fibers connect to the primary visual cortex in the occipital lobes
- Other optic tract fibers send branches to the midbrain, ending in superior colliculi (initiating visual reflexes)

Visual Pathway

- A small subset of ganglion cells in the retina contain melanopsin (circadian pigment), which projects to:
  - Pretectal nuclei (involved with pupillary reflexes)
  - Suprachiasmatic nucleus of the hypothalamus, the timer for daily biorhythms



The visual fields of the two eyes overlap considerably.

Note that fibers from the lateral portion of each retinal field do not cross at the optic chiasma.

Figure 15.19a

Depth Perception

- Both eyes view the same image from slightly different angles
- Depth perception (three-dimensional vision) results from cortical fusion of the slightly different images

Retinal Processing

- Several different types of ganglion cells are arranged in doughnut-shaped receptive fields
  - On-center fields
    - Stimulated by light hitting the center of the field
    - Inhibited by light hitting the periphery of the field
  - Off-center fields have the opposite effects
- These responses are due to different receptor types for glutamate in the “on” and “off” fields

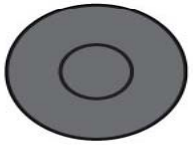
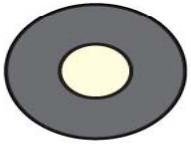
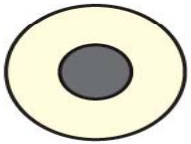
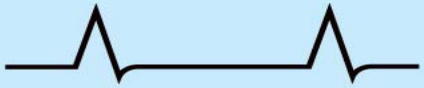
Stimulus pattern (portion of receptive field illuminated)	Response of on-center ganglion cell during period of light stimulus	Response of off-center ganglion cell during period of light stimulus
No illumination or diffuse illumination (basal rate) 		
Center illuminated 		
Surround illuminated 		

Figure 15.20

Thalamic Processing

- Lateral geniculate nuclei of the thalamus
  - Relay information on movement
  - Segregate the retinal axons in preparation for depth perception
  - Emphasize visual inputs from regions of high cone density
  - Sharpen contrast information

Cortical Processing

- Two areas in the visual cortex

1. Striate cortex (primary visual cortex)
   - Processes contrast information and object orientation
2. Prestriate cortices (visual association areas)
   - Processes form, color, and motion input from striate cortex

- Complex visual processing extends into other regions
  - Temporal lobe—processes identification of objects
  - Parietal cortex and postcentral gyrus—process spatial location