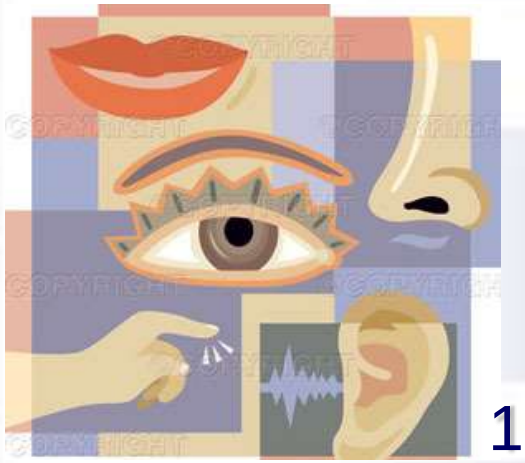
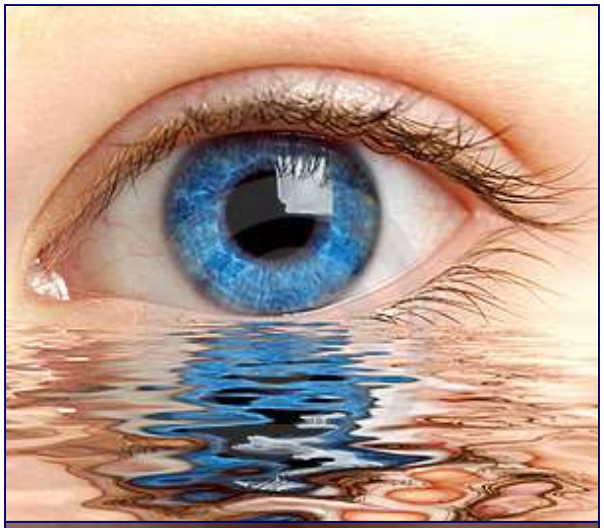


Visual Apparatus

1. Visual organs – embryonic development
2. Anatomy of the eyeball:
   - ✓ fascial sheath – fibrous and vascular tunics, retina
   - ✓ ocular refractive media – aqueous humor, vitreous body, lens
3. Accessory visual apparatus
4. Visual pathway

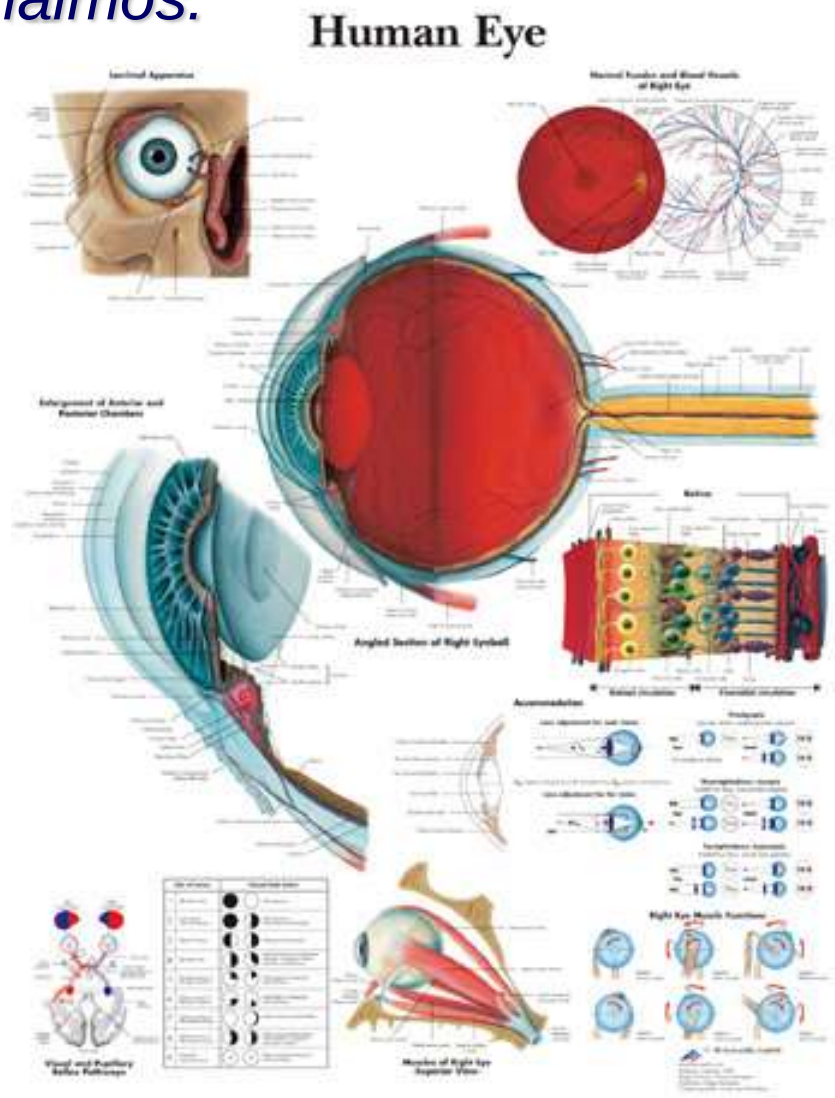
Human visual organs

- **The eye – some amazing facts:**
  - ✓ the eyeball of a human weighs approximately 28 g;
  - ✓ although only 1/6th of it is exposed to the outside world, about half of our brain is involved in the seeing process – humans are thus very much visual animals!
  - ✓ the only part of our body that can function at 100% ability at any moment, day or night, without rest;
  - ✓ most complex organs we possess – composed of more than 2 million working parts;
  - ✓ the external muscles that move the eyes are the strongest muscles in the human body for the job that they have to do. They are 100 times more powerful than they need to be!
  - ✓ the retina contains 120 million rods for "night vision", and 8 million cones that are colour sensitive and work best under daylight conditions;
  - ✓ contributes towards 85% of our total knowledge – can process 36,000 bits of information every hour.



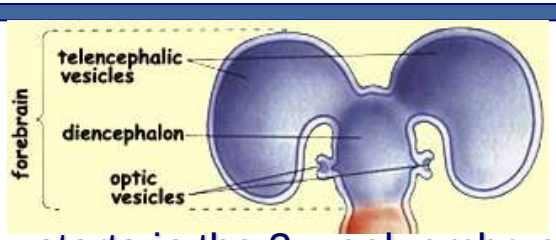
Anatomy of the eye

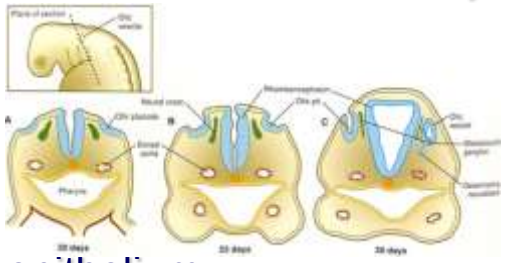
- **The eye** – Lat. *oculus*, Gr. *ophthalmos:*
  - ✓ **eyeball**
    - ➢ **three ocular coats**
      - ○fibrous tunic
        - sclera
        - cornea
      - ○vascular tunic (uveal tract)
        - choroid
        - ciliary body
        - iris
      - ○retina
    - ➢ **ocular refractive media**
      - ○aqueous chamber&humor
      - ○vitreous body
      - ○lens
  - ✓ **accessory structures**
    - ➢ extraocular muscles
    - ➢ eyebrows and eyelids
    - ➢ lacrimal apparatus



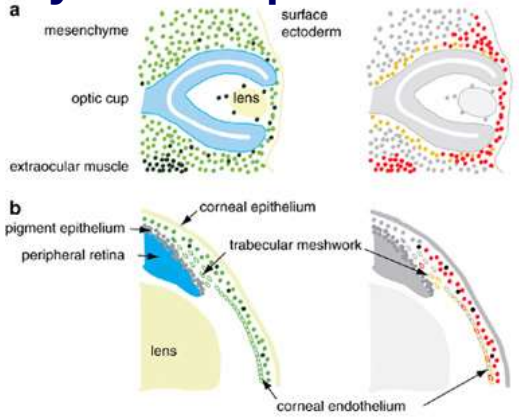
Eye development

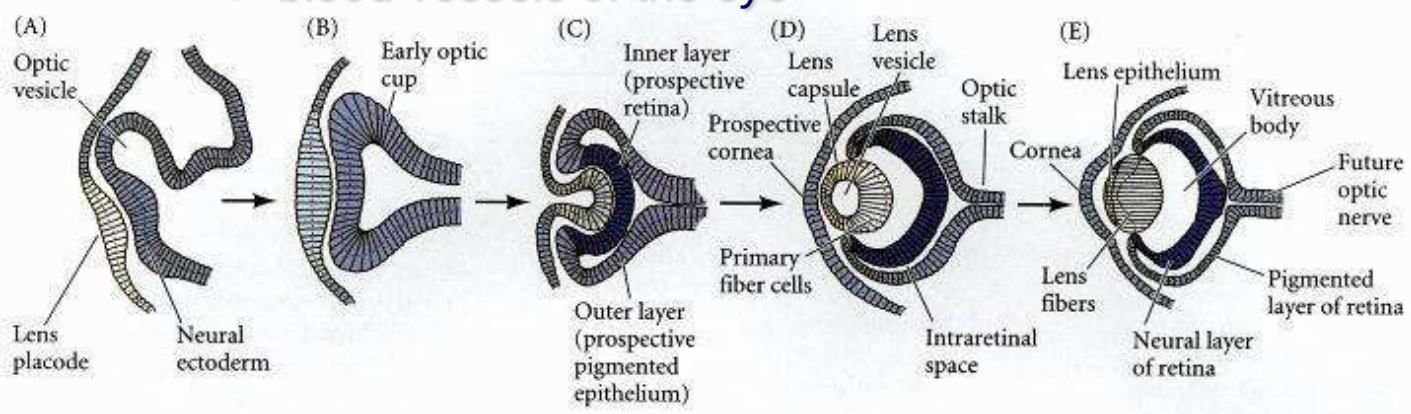
- **Eye rudiments:**
  - ✓ neural tube
    - ➢ optic vesicles
      - optic sulcus – starts in the 3-week embryo
    - ➢ neuroepithelium
      - lens placode
    - ➢ optic cup
      - retina
      - retinal pigment epithelium
  - ✓ periocular mesenchyme
    - ➢ cornea&sclera
    - ➢ iris&ciliary body
    - ➢ blood vessels of the eye

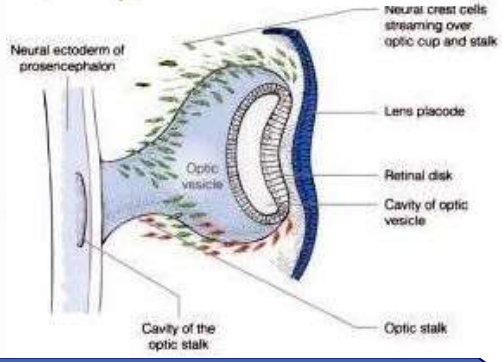




NB: **Pax6 is a master regulator for eye development in humans!**

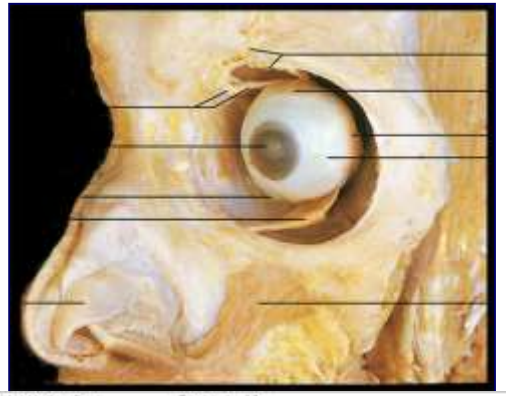


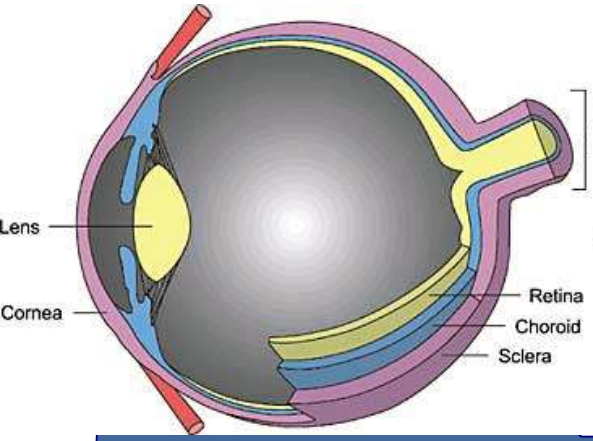


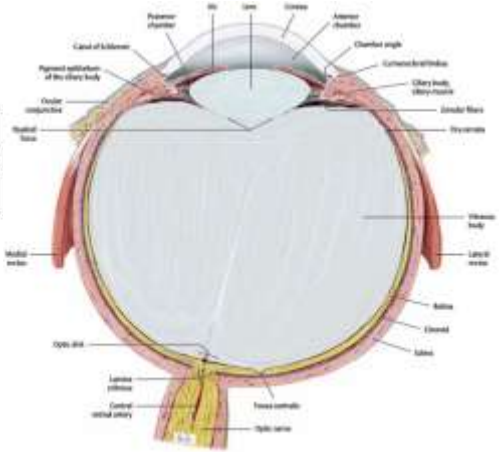


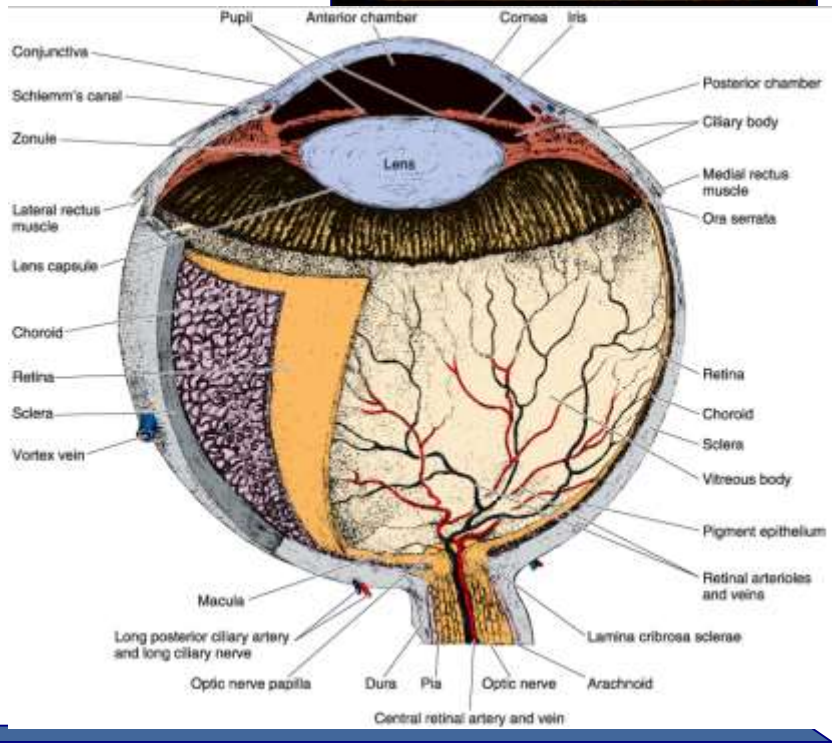
Eyeball

- **Eyeball – the peripheral organ of sight:**
  - ✓ embedded in the fat of the orbit
  - ✓ enveloped by a fascial sheath (capsule of *Tenon*)
  - ✓ anterior and posterior poles ⇨ optic (visual) axis
  - ✓ approximately spherical "ball" – dimensions:
    - ➢ vertical diameter – 23.5 mm
    - ➢ anterioposterior diameter – 24 mm (17.5 mm at birth)
  - ✓ three coats (tunics):
    - ➢ fibrous tunic
    - ➢ vascular, pigmented tunic
    - ➢ nervous layer, retina
  - ✓ content – ocular refractive media



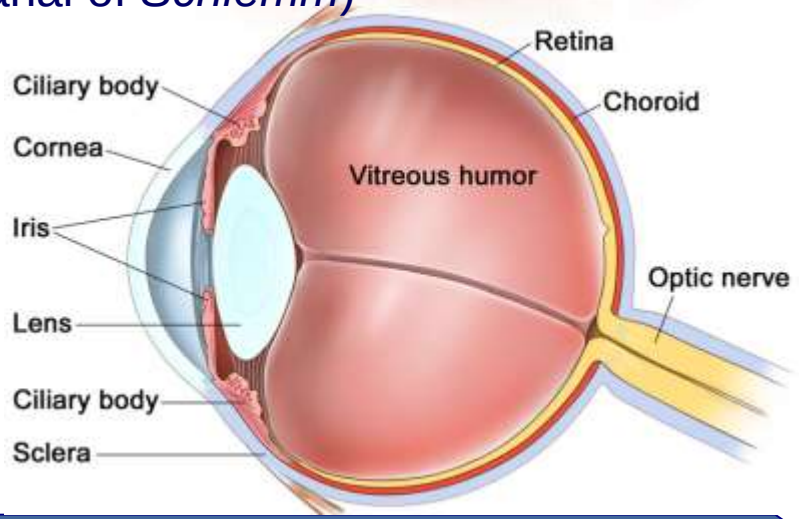


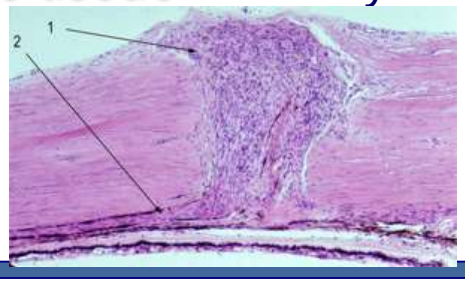




Ocular fibrous tunic

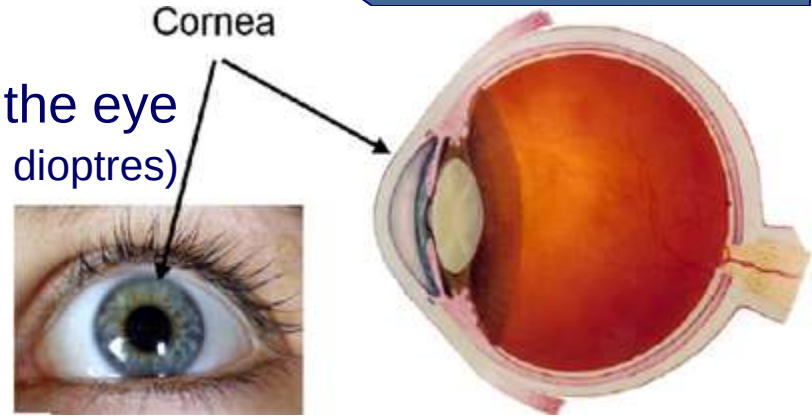
- **Sclera (tunica sclera)** – Gr. *skleros*, hard:
  - ✓ the outer layer of the eyeball – "the white of the eye"
  - ✓ the posterior five-sixths of the connective tissue coat of the globe
  - ✓ firm protective membrane ⇨ maintains the shape of the globe
  - ✓ smooth, provides an attachment for the extraocular muscle insertions
  - ✓ perforated by many nerves and vessels ⇨ lamina cribrosa, sinus venosus sclerae (canal of *Schlemm*)
  - ✓ opaque with varying thickness:
    - 1 mm at the posterior pole
    - 0.3 mm just behind muscle insertions
  - ✓ fibrous connective tissue – four layers:
    - episclera
    - stroma
    - lamina fusca
    - endothelium

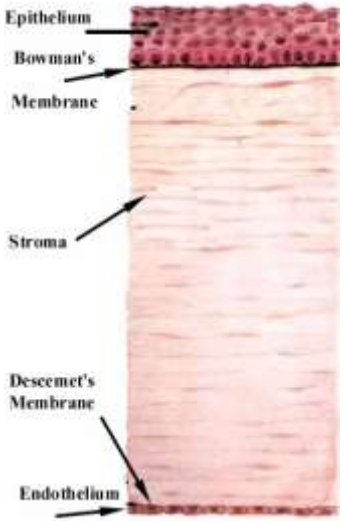


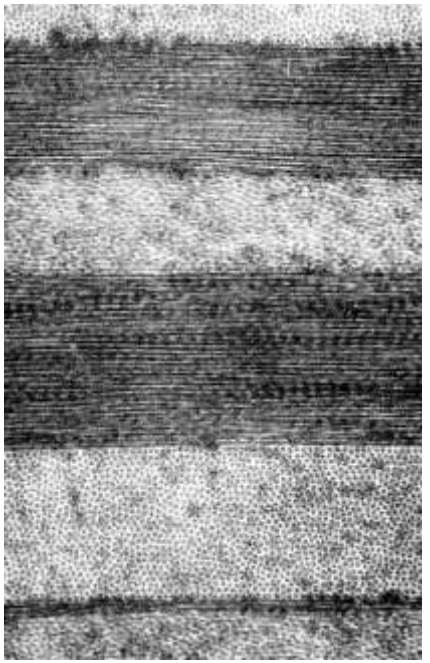


Ocular fibrous tunic

- **Cornea** – "kerat-", Gr. *κέρας*, horn
  - ✓ projecting and transparent front part of the eye
    ⇨ refracts (together with the lens) light (~ 43 dioptres)
  - ✓ the anterior one-sixths
    of the connective tissue coat of the globe
  - ✓ dense with varying thickness:
    - ➢ ~1.2 mm round its periphery
    - ➢ 0.5-0.6 mm at its centre
  - ✓ non-vascular structure ⇨ surface ectodermal origin
  - ✓ richly innervated ⇨ corneal (blink) reflex
  - ✓ structurally – five layers:
    - ➢ corneal **epithelium**
    - ➢ anterior limiting membrane (of ***Bowman***)
    - ➢ substantia propria (corneal **stroma**)
    - ➢ posterior limiting membrane (of ***Descemet***)
    - ➢ **endothelium** of the anterior chamber



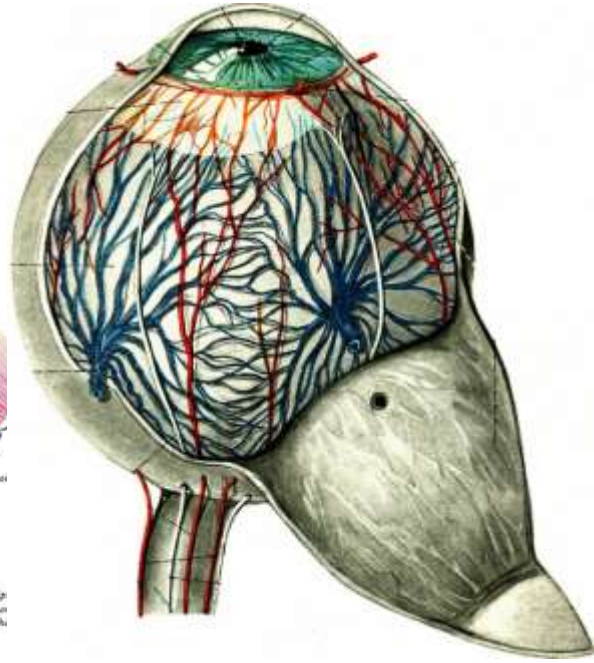


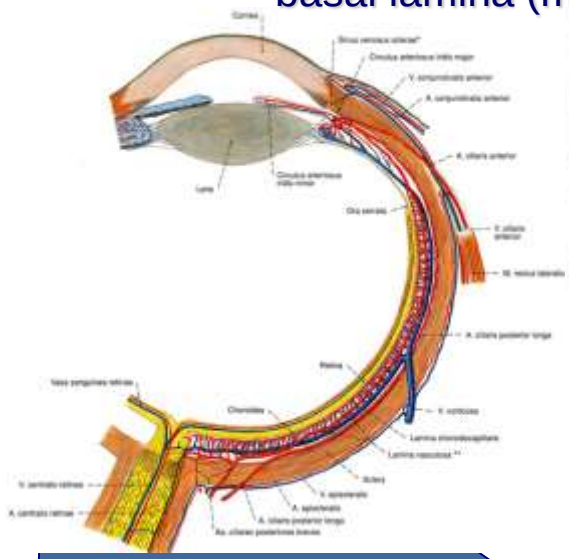


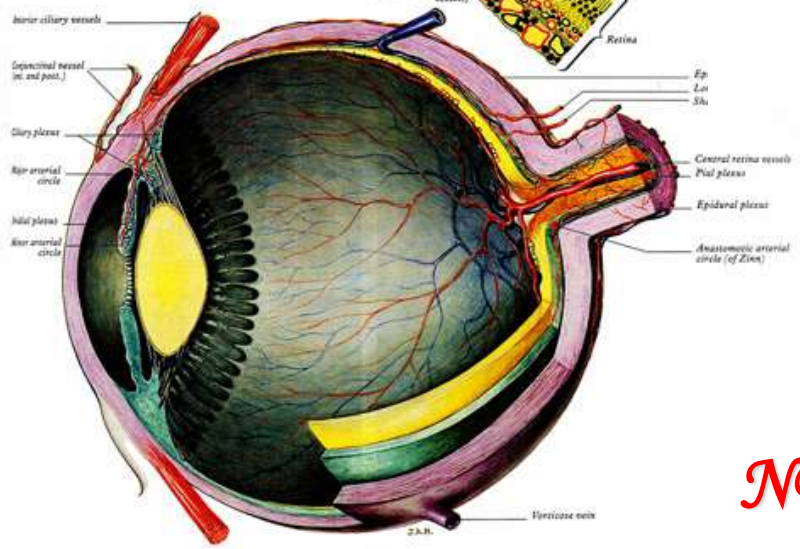
*NB: The mnemonic "**EBSDE**in", read as "**Ebstein**" can be used to remember the layers in sequence!*

Vascular tunic (uveal tract)

- **Choroid** – ⅔ of the uveal tract surface ~ 0.5 mm in humans:
  - ✓ thin, highly vascular coat, dark brown or chocolate
  - ✓ dense capillary plexus – provides oxygen and nourishment to the outer layers of the retina
  - ✓ composition:
    - ➢ suprachoroid lamina – ~ 30 μm thick
    - ➢ choroid proper:
      - vascular lamina
      - capillary lamina (choroidocapillaris)
      - basal lamina (membrane of *Bruch*)



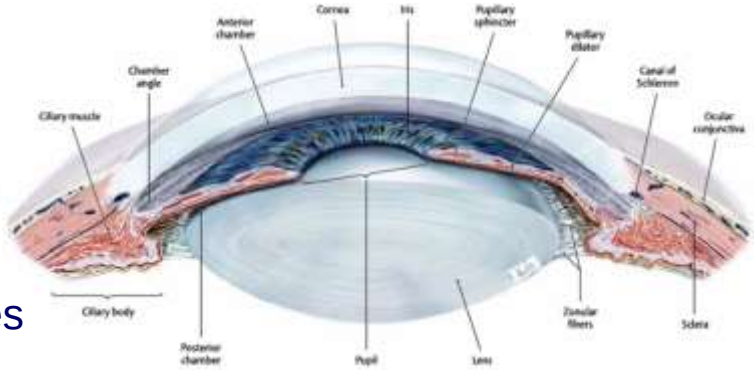




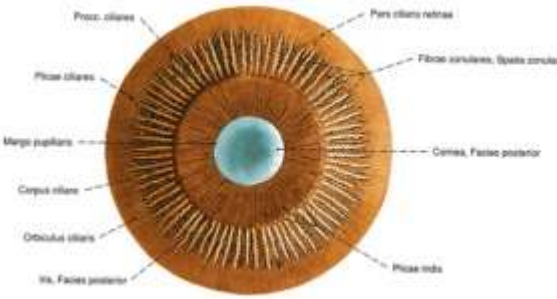
NB: uva, Lat. grape

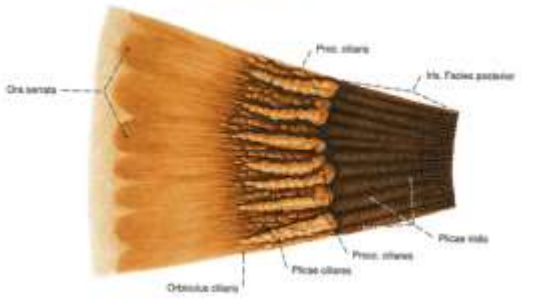
Vascular tunic (uveal tract)

- **Ciliary body** – Lat. *cilium*, eyelid:
  - ✓ the circumferential tissue inside the eye
  - ✓ triangular in horizontal section
  - ✓ coated by a double layer, the ciliary epithelium
    - ➢ superficial lamina – columnar cells
    - ➢ deep layer – cuboidal cells with pigment granules

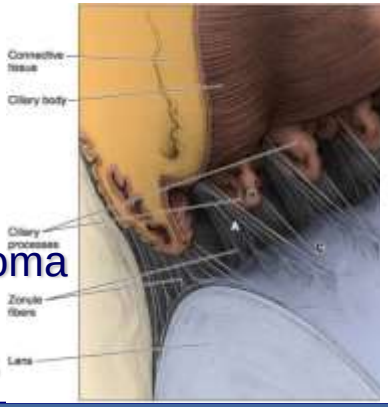


  - ✓ composition:
    - ➢ ciliary ring, *orbiculus ciliaris (pars plana)* – 3.5-4 mm
    - ➢ *corona ciliaris (pars plicata)*
      - 70-80 ciliary processes ⇨ aqueous humor
      - ciliary plicae
    - ➢ ciliary muscle ⇨ zonule of *Zinn* ⇨ lens (suspensory ligament)
      - meridional (muscle of *Brücke*)
      - radial (oblique) fibers
      - circular (muscle of *Müller*)





  - ✓ functions:
    - ➢ accommodation
    - ➢ aqueous humor production ⇨ glaucoma
    - ➢ production and maintenance of the lens zonules



Vascular tunic (uveal tract)

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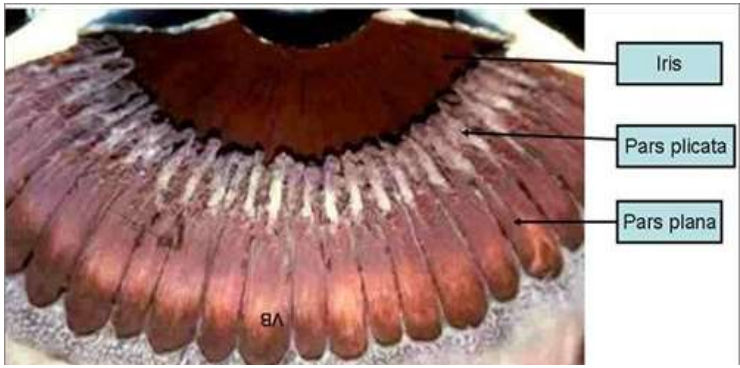
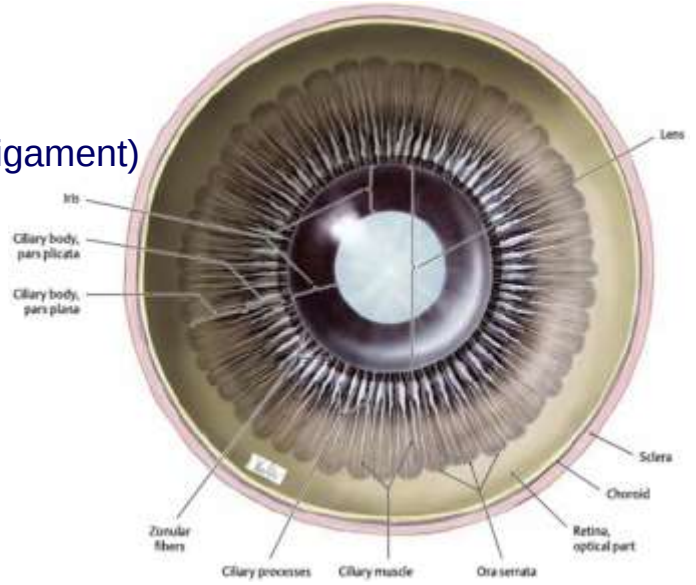
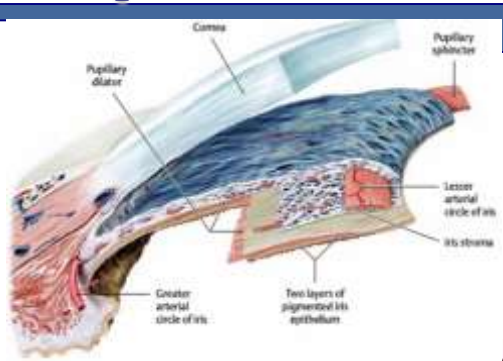
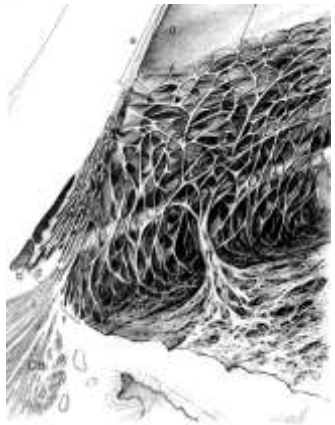


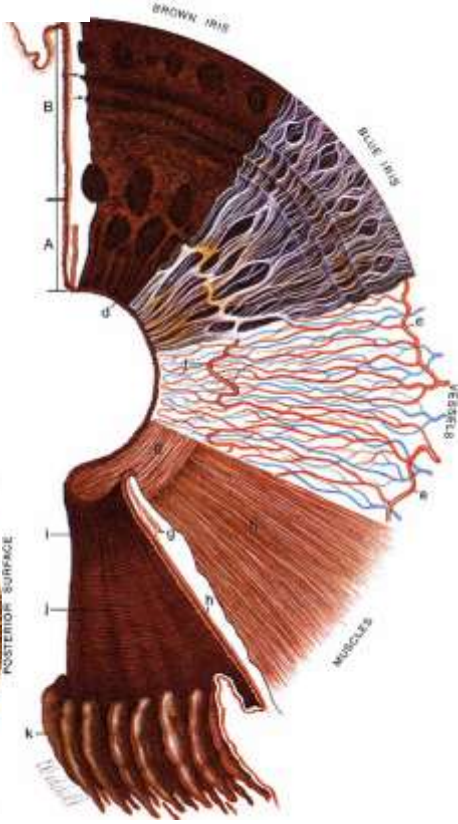


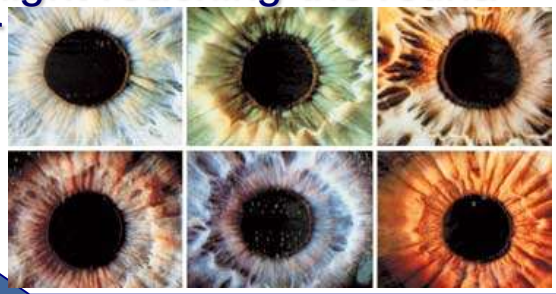
Vascular tunic (uveal tract)

- **Iris –** *Greek* goddess of the rainbow:
  - ✓ opaque, pigmented diaphragm
  - ✓ two major regions:
    - ➢ pupillary zone ⇨ pupil
      - a sphincter muscle (sphincter pupillae)
      - a set of dilator muscles (dilator pupillae)
    - ➢ ciliary zone ⇨ ciliary body
  - ✓ iridocorneal angle ⇨ Fontana's spaces
  - ✓ microscopic structure:
    - ➢ pigmented fibrovascular tissue (stroma)
    - ➢ pigmented epithelial cells
  - ✓ functions:
    - ➢ control of the diameter and size of the pupil
    - ➢ the amount of light reaching the retina
    - ➢ responsible for the "eye color"



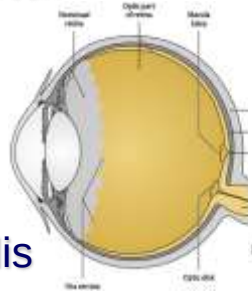


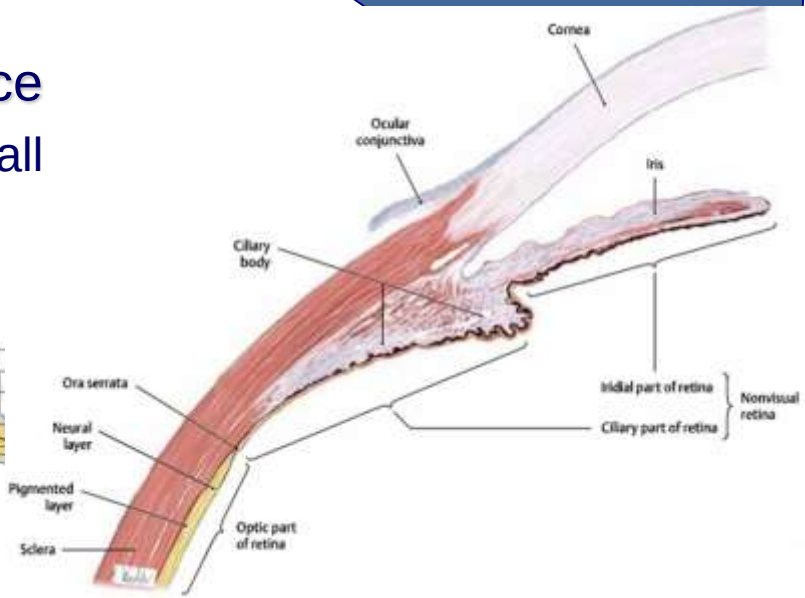




Retina

- **Retina –** Lat. *rete,* net:
  - ✓ approx. 72% of the eyeball internal surface
  - ✓ neuronal, light-sensitive layer of the eyeball
  - ✓ two principal parts – *ora serrata:*
    - ➢ anterior "blind" part
      - ciliary part
      - iridial part
    - ➢ posterior optic part
      - macula lutea ⇨ fovea centralis
      - optic disc – "blind spot"

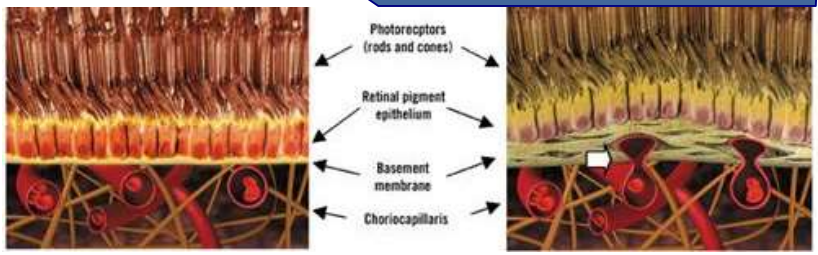


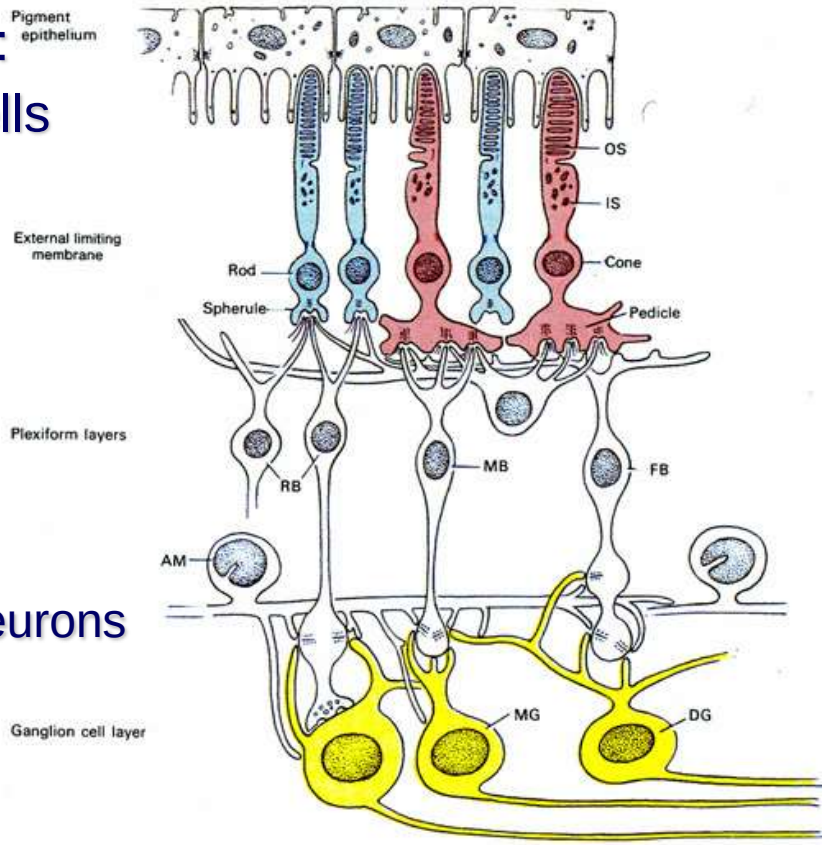


  - ✓ structure – two major layers:
    - ➢ outer *stratum pigmentosum* ⇨ pigment epithelium
    - ➢ inner *stratum nervosum*
  - ✓ functions:
    - ➢ the same *function* as the film in a camera
      - receives the image seen through our eye
      - converts a light signal into a neural signal ("signal transduction")
      - transmits this image through the optical nerve to the brain

Structure of the retina

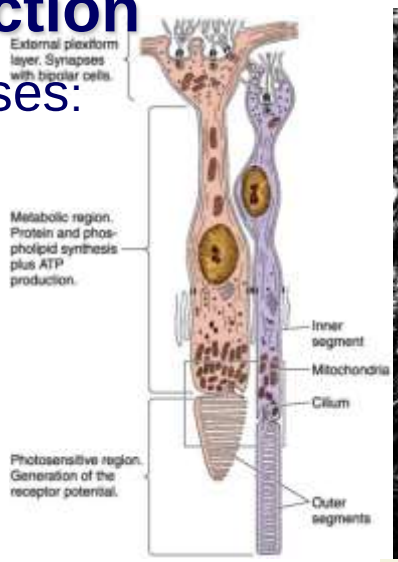
- **three layers of retinal neurons**
- **two layers of synapses**
- **retinal pigment epithelium**
  - ✓ 4-6 million hexagonal cells – fuscin
- **neural part of retina** – 5 cell types:
  - ✓ neuroepithelial (**photoreceptor**) cells
    – in *stratum neuroepitheliale*
    - ➢ **rods**
    - ➢ **cones**
  - ✓ **bipolar cells**
    – in *stratum ganglionare retinae*
  - ✓ **ganglion cells**
    – in *stratum ganglionare nervi optici*
  - ✓ **horizontal cells** – GABAergic interneurons
    – in *stratum plexiforme externum*
  - ✓ **amacrine cells**
    – in *stratum plexiforme internum*

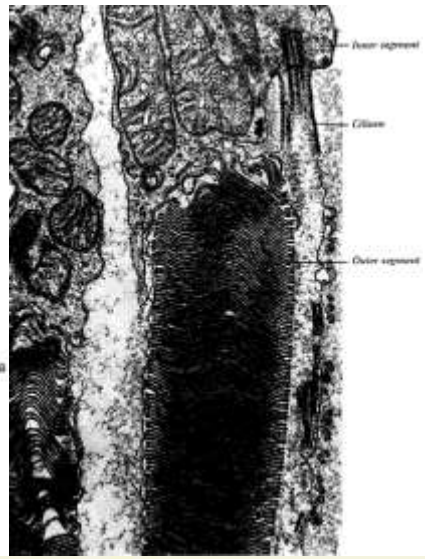


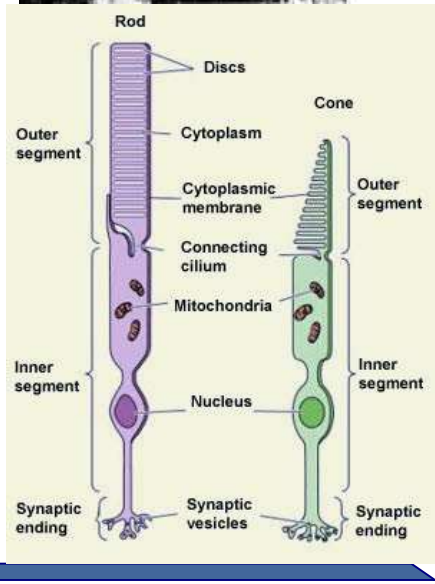


Photoreceptor cells

- **neurons capable of phototransduction**
- classic photoreceptors – two main classes:
  - ✓ **rods** – 75 to 150 million
    - ➢ adapted for low light "night vision"
    - ➢ contain rhodopsin
  - ✓ **cones** – ~ 7 million
    - ➢ function well in bright light "daylight"
    - ➢ detect colors – three different types
      - responding to short (blue) light
      - responding to medium (green) light
      - responding to long (yellow-red) light
  - ✓ photosensitive ganglion cells – 1-2% of all (1.3 million) ganglion cells in humans
- the same basic structure:
  - ✓ cell body with nucleus in outer nuclear layer
  - ✓ outer segment (discs), stalk (cilium), inner segment (mitochondria) in photoreceptor layer

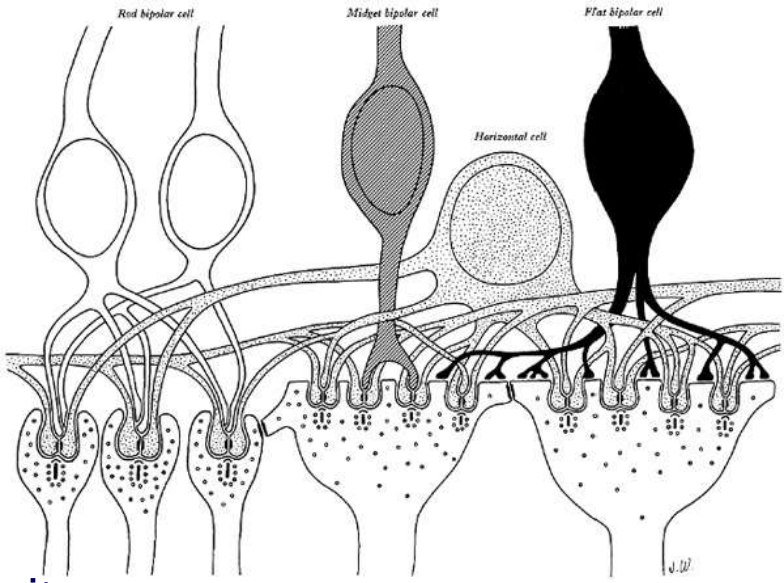


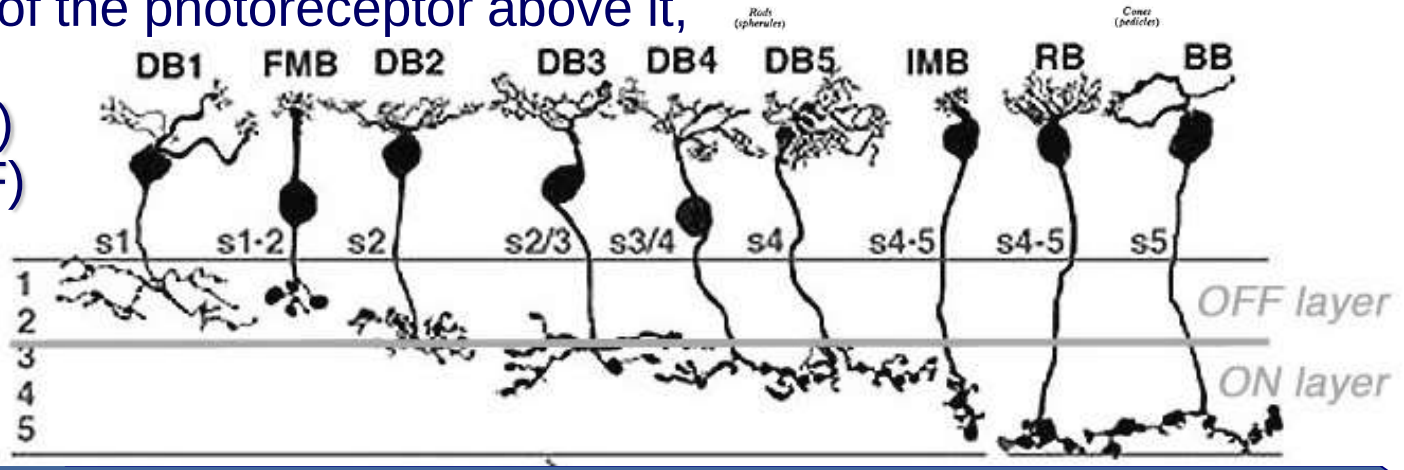




Bipolar cells

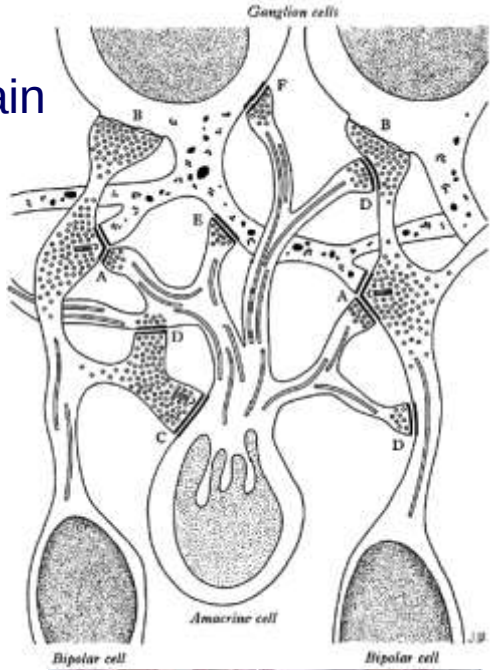
- transmit signals from the photoreceptors to the ganglion cells – interneurons
- three types bipolar neurons:
  - ✓ rod bipolar cells
  - ✓ midget (cone) cells
  - ✓ flat bipolar cells
- common bipolar cell structure:
  - ✓ a central cell body in inner nuclear layer
  - ✓ outer process
    - ➢ makes synapse with either rods or cones
  - ✓ inner process
    - ➢ accepts synapses from horizontal cells
- direct innervation of the photoreceptor above it, either through a metabotropic (ON) or ionotropic (OFF) receptor

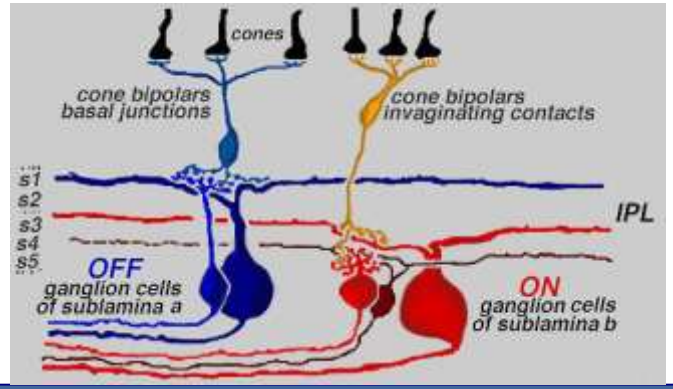


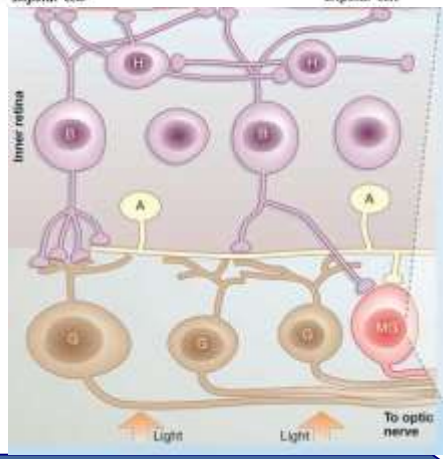


Ganglion cells

- receive visual information from photoreceptors via bipolar and amacrine cells
- transmit visual information from retina to several regions in brain
- ~ 1.2 to 1.5 million retinal ganglion cells in the human retina
- five main classes of ganglion neurons:
  - ✓ midget ganglion cells – monosynaptic; A cells
  - ✓ parasol (magnocellular; B cells)
  - ✓ polysynaptic (rod and flat) ganglion cells
  - ✓ photosensitive ganglion cells
- structure:
  - ✓ a central cell body in ganglionic cell layer
  - ✓ inner process
    - ➢ makes synapse with either bipolar or amacrine cells
  - ✓ outer process – long axon extending into the brain
    - ➢ forms the optic nerve

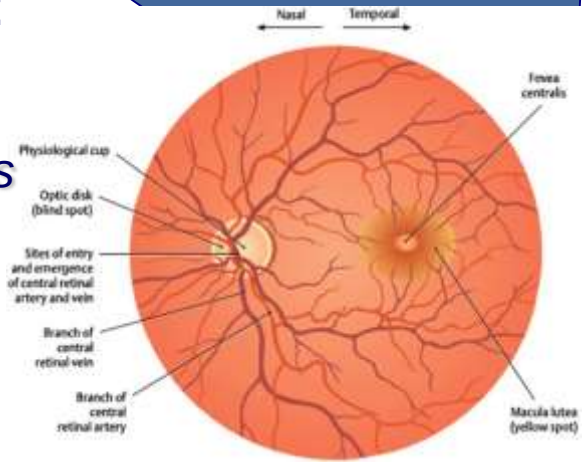


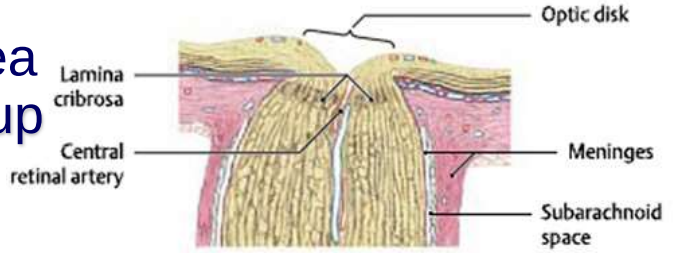


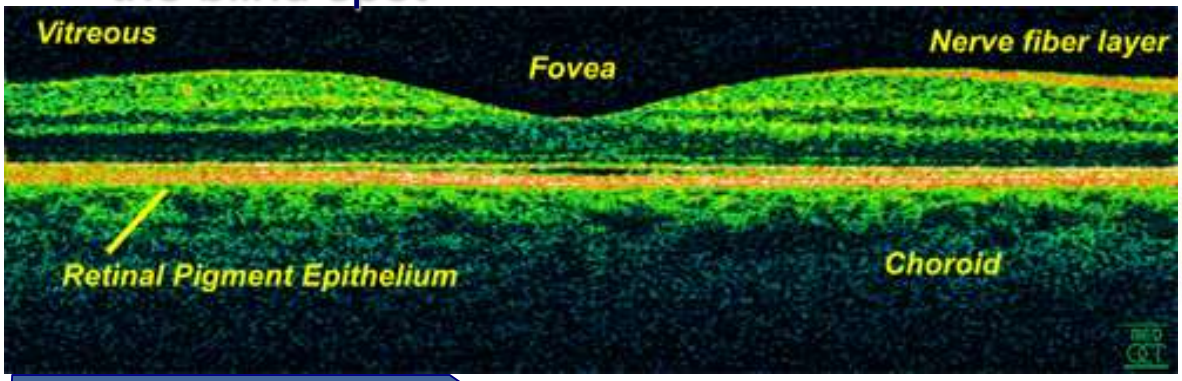


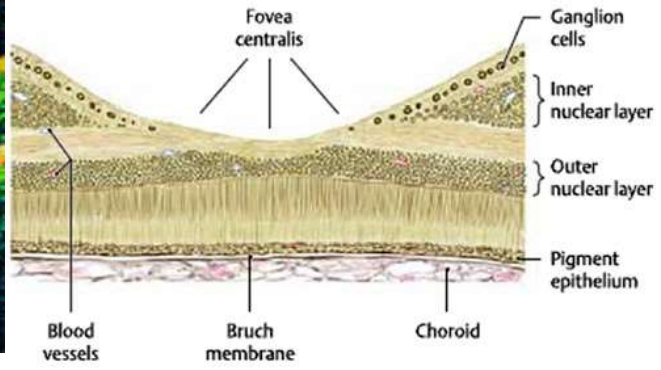
Macular area

- macula lutea (Lat.*macula*, "spot" + *lutea*, "yellow"):
  - ✓ oval-shaped highly pigmented yellow spot with diameter of around 5 mm
  - ✓ centre of the macula is the foveal pit, *fovea centralis*
  - ✓ the fovea contains the largest concentration of cones in the eye ⇨ allows for the sharpest vision
- optic disk (papilla):
  - ✓ location where ganglion cell axons exit the eye to form the optic nerve
  - ✓ placed 3 to 4 mm to the nasal side of the fovea
  - ✓ vertical oval with a central depression, optic cup
  - ✓ contains no light sensitive receptor cells – "the blind spot"



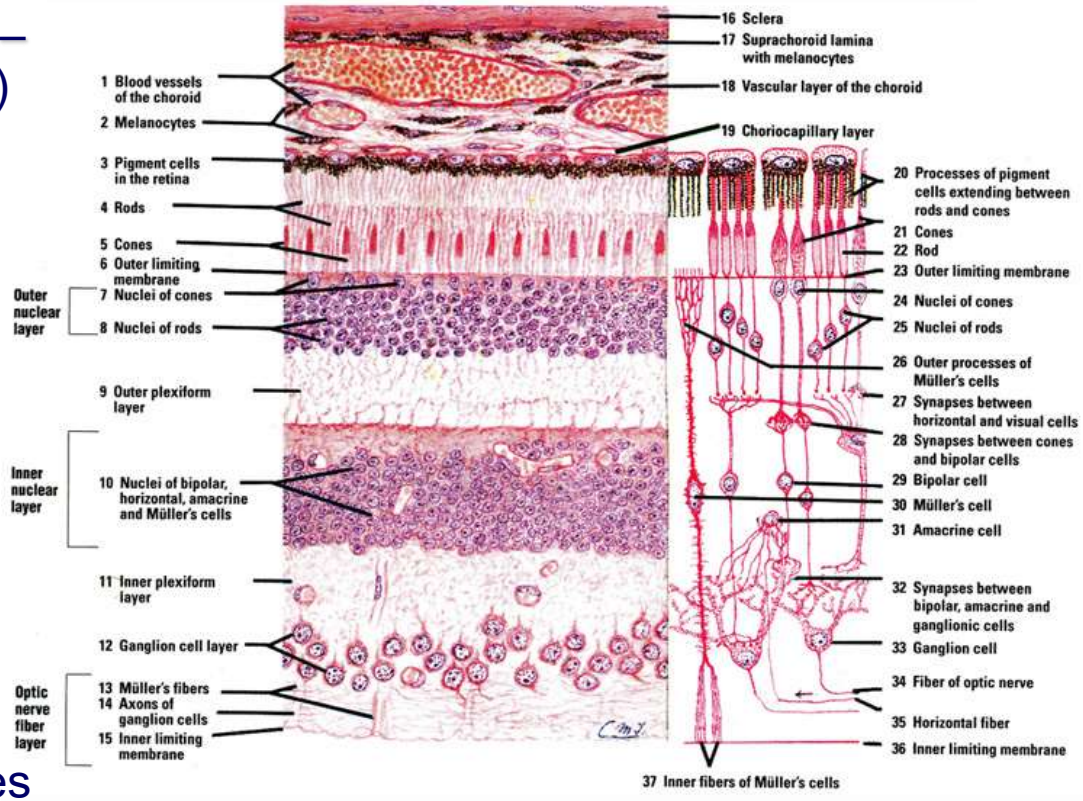






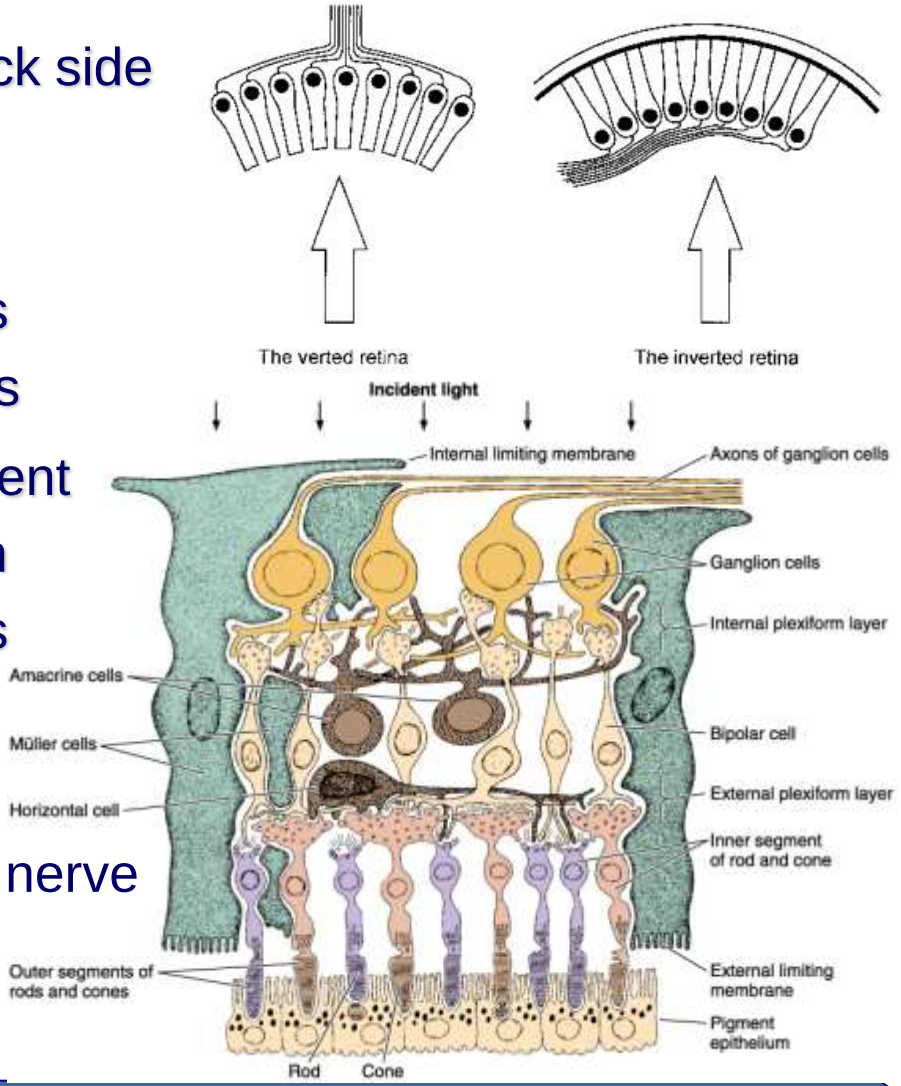
Microscopic structure of the retina

- **retina** – ≤0.5 mm thick
- **ten distinct layers:**
  - ✓ retinal pigment epithelium
  - ✓ photoreceptor layer – rods/cones external processes
  - ✓ external limiting membrane – retinal glyocytes (Müller's cells)
  - ✓ outer nuclear layer – rods/cones cell nuclei
  - ✓ outer plexiform layer fiber layer of *Henle* in macula
  - ✓ inner nuclear layer – bipolar, horizontal and amacrine cells
  - ✓ inner plexiform layer
  - ✓ ganglionic cell layer
  - ✓ optic nerve fiber layer
  - ✓ inner limiting membrane – Müller cell footplates&astrocytes



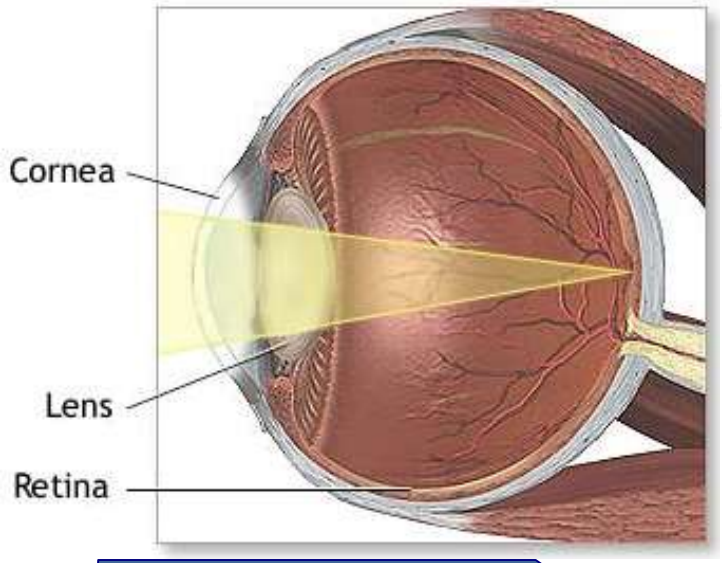
Inverted retina

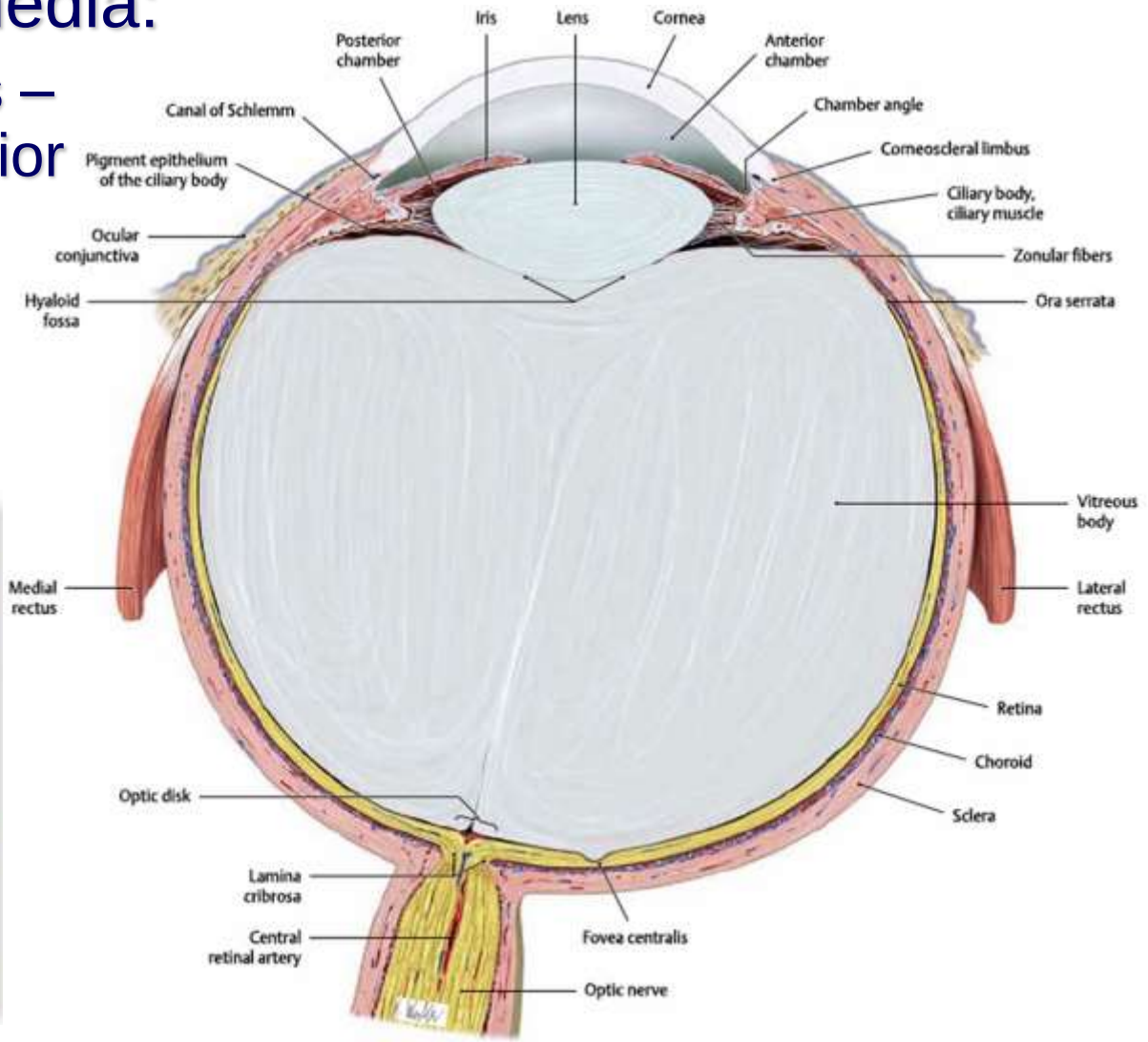
- ‘inverted’ arrangement of the vertebrate retina:
  - ✓ the light sensing cells sit at the back side of the retina
  - ✓ light has to pass through several inner layers of its neural apparatus before reaching the photoreceptors
  - ✓ an image of the external environment is thus focused on the retina which transduces light into neural signals
  - ✓ neural impulses pass back from the photoreceptor layer through the ganlionic cell layer to the optic nerve
  - ✓ opposite directions of light and nerve impulse!



Ocular refractive media

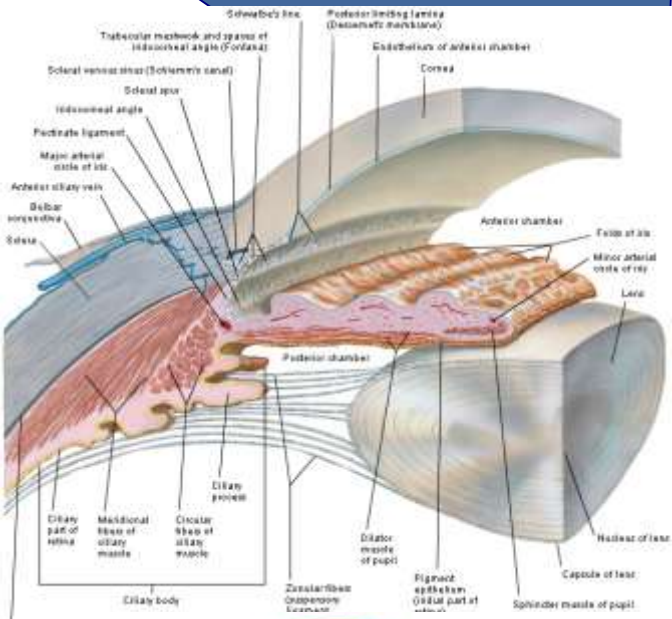
- Ocular refractive media:
  - ✓ aqueous chambers – anterior and posterior
    - ➢ aqueous humor
  - ✓ vitreous chamber
    - ➢ vitreous body
  - ✓ lens

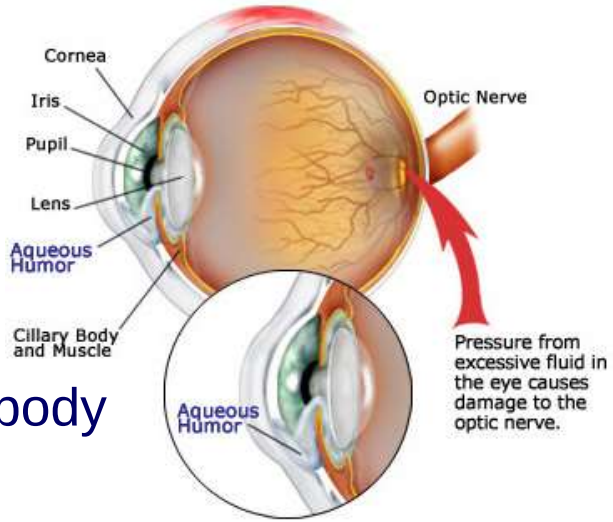




Aqueous chambers and humor

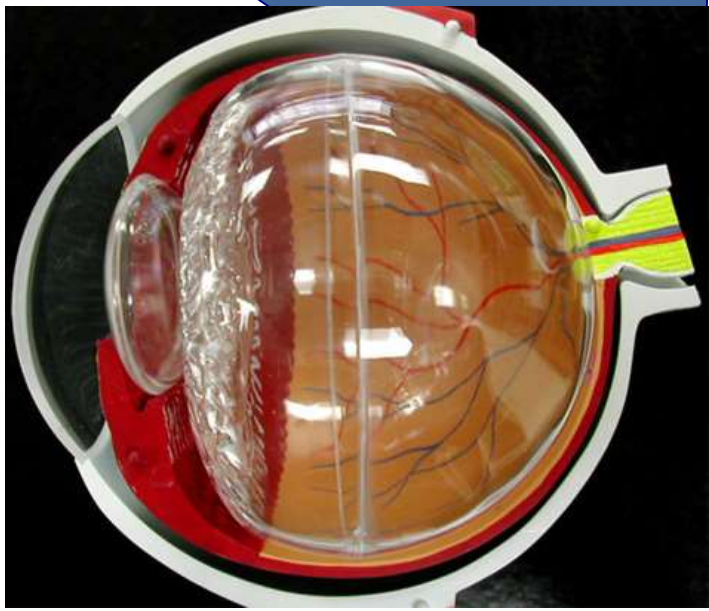
- aqueous chambers:
  - ✓ anterior – between the posterior surface of the cornea and the iris
  - ✓ posterior – between the iris and the front face of the vitreous body
- aqueous humor:
  - ✓ provides nutrients to the lens and corneal endothelium
  - ✓ maintains the convex shape of the cornea
  - ✓ carries away waste products from metabolism
- composition:
  - ✓ water – 99%, glucose, amino acids
  - ✓ ions: HCO_3^-; Cl^-; Na^+; K^+; Ca^{2+}; PO_4^{3-}
  - ✓ proteins: albumin, β-globulins
- production and drainage:
  - ✓ secreted into posterior chamber by the ciliary body
  - ✓ drains into Schlemm's canal ⇨ glaucoma

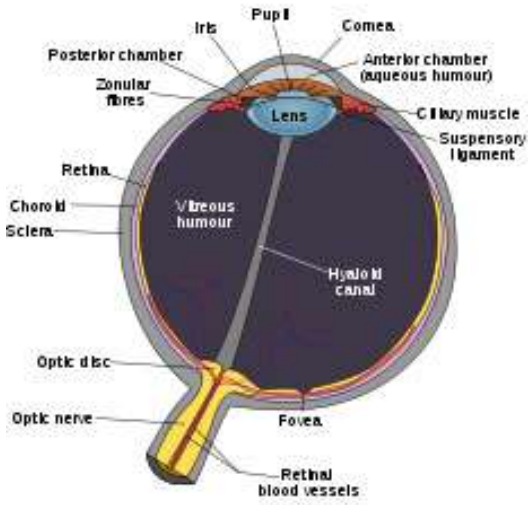




Vitreous chamber and body

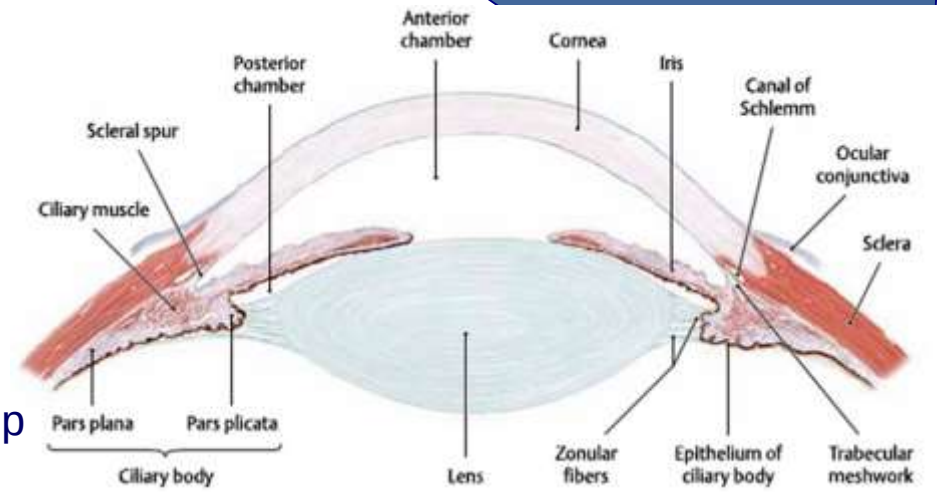
- vitreous chamber – ~4/5 of the eyeball
  - ✓ the gel in vitreous chamber is stagnant
- vitreous body:
  - ✓ transparent, colourless, gelatinous mass
  - ✓ produced by certain retinal cells
- structure:
  - ✓ vitreous (hyaloid) membrane peripherally
  - ✓ hyaloid canal centrally
  - ✓ very few cells – phagocytes and hyalocytes
  - ✓ contains no blood vessels
- composition:
  - ✓ water – 99%
  - ✓ some salts
  - ✓ little glycoprotein and hyaluronate
  - ✓ vitrosin (a type of collagen)
- functions:
  - ✓ refracting media
  - ✓ helps to keep the retina in place

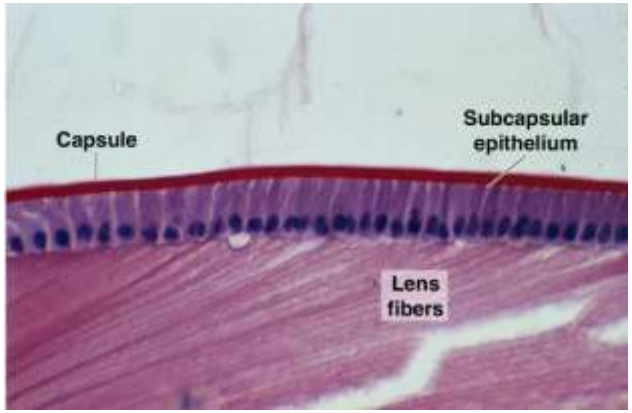


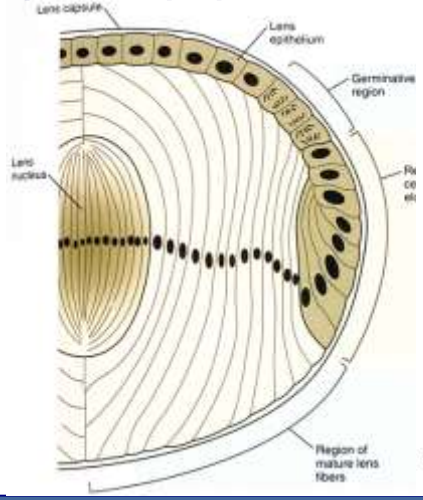


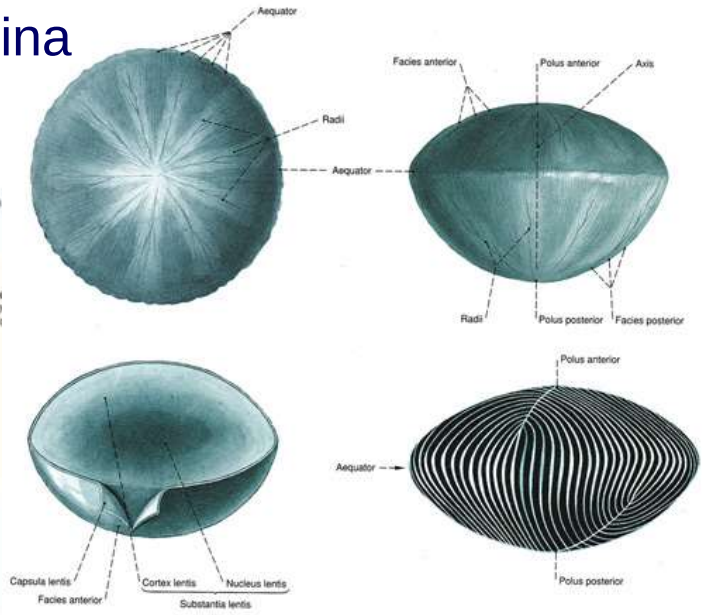
Lens

- lens:
  - ✓ transparent, biconvex body
- structure:
  - ✓ anterior and posterior poles
  - ✓ equator and capsule
  - ✓ soft cortical substance
  - ✓ firm, central part, nucleus
  - ✓ contains no true elastic tissue
  - ✓ lens fibers (cells) – superficial and deep
- function:
  - ✓ helps to refract light to be focused on the retina
  - ✓ contributes about 15-18 dioptres (⅓) to the total dioptric power



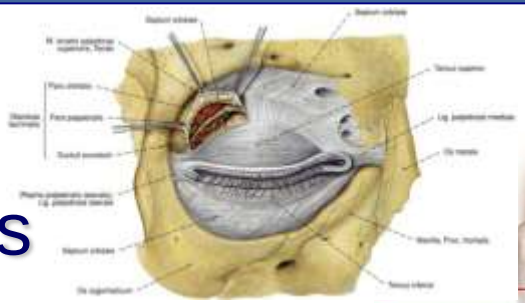


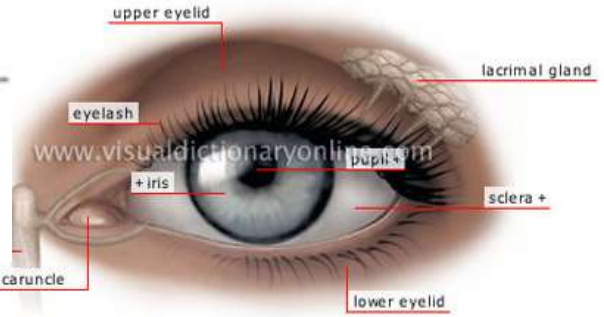


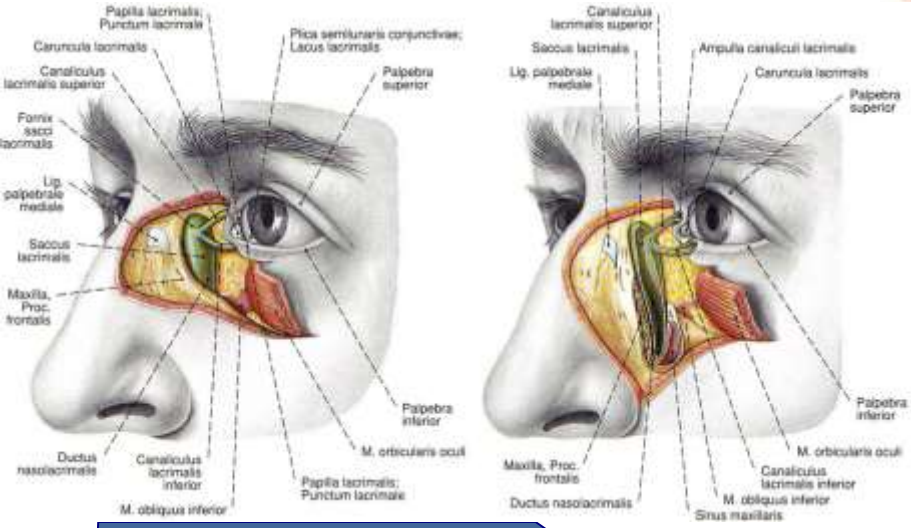


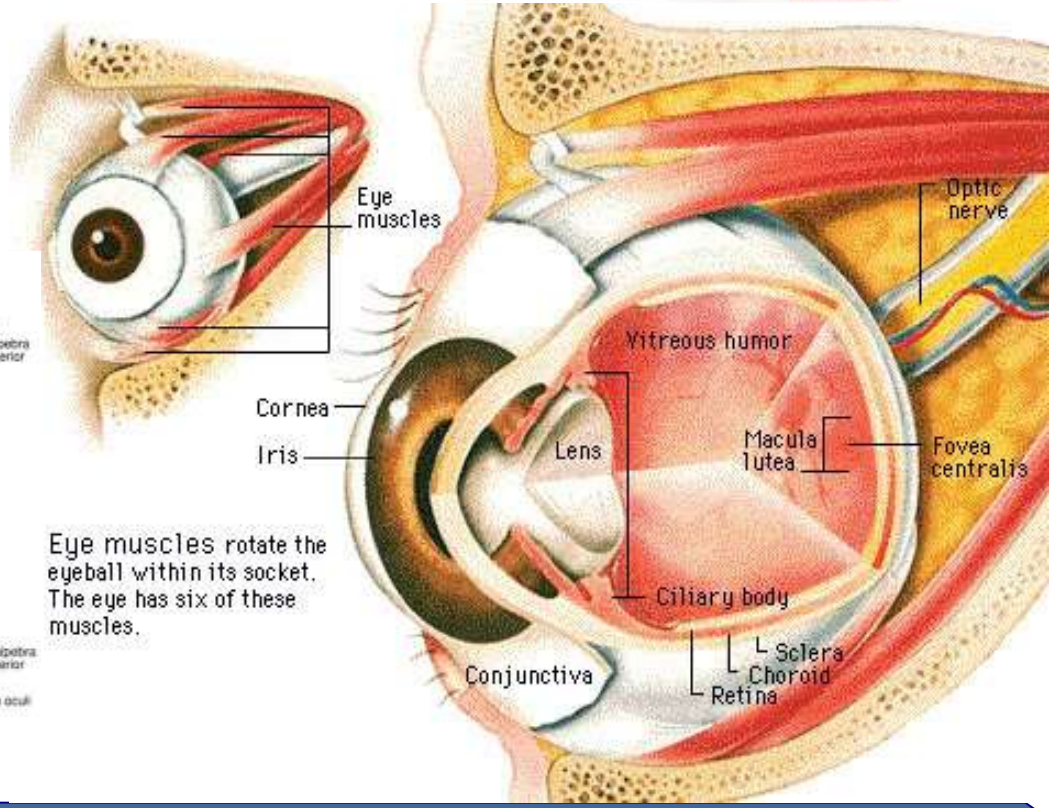
Accessory visual apparatus

- ✓ Extraocular muscles
- ✓ Eyebrows and eyelids
- ✓ Conjunctiva
- ✓ Lacrimal apparatus





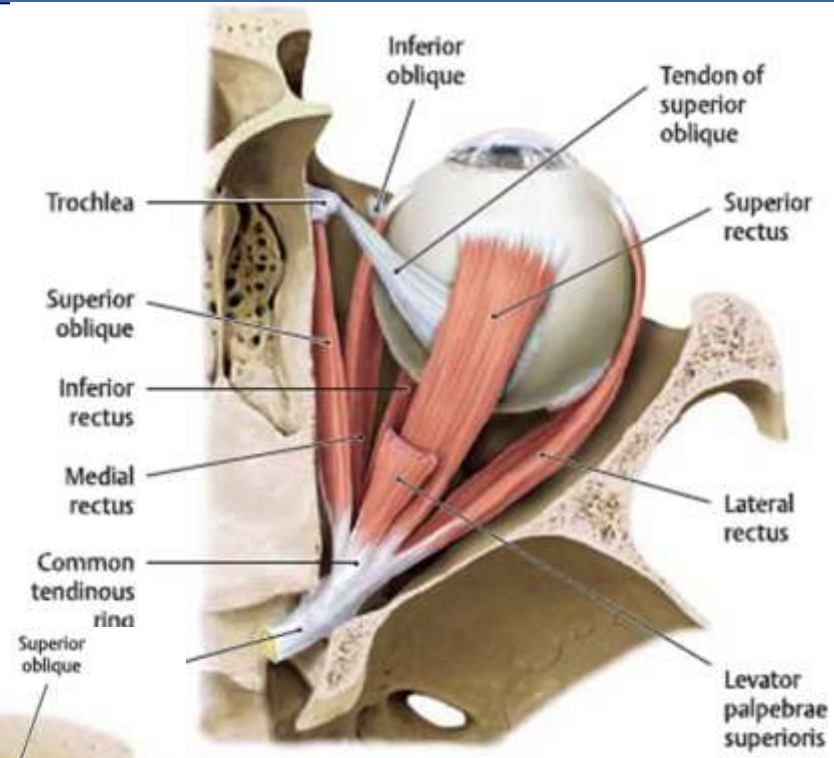


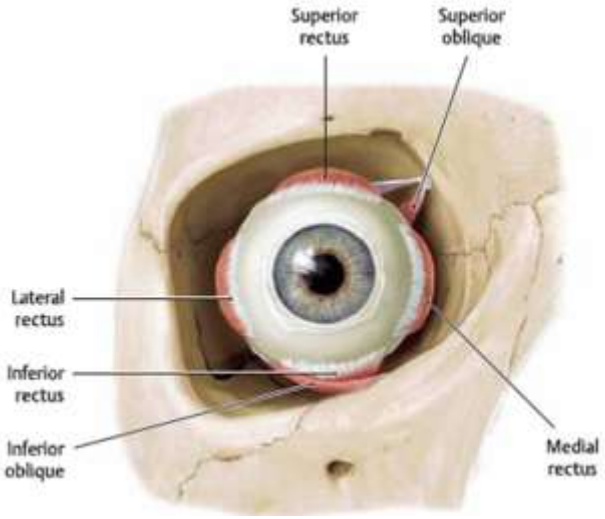


Eye muscles rotate the eyeball within its socket. The eye has six of these muscles.

Extraocular muscles

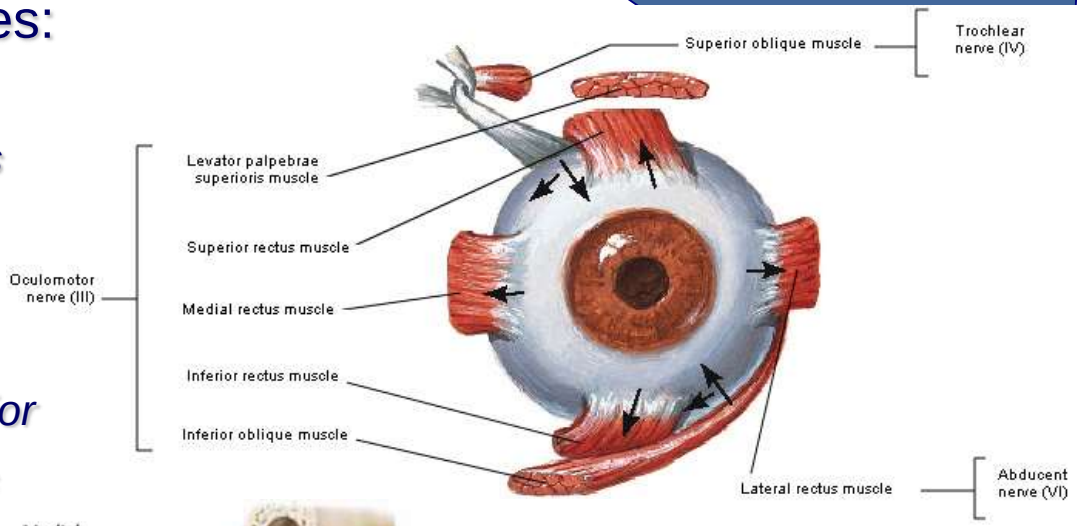
- extraocular muscles:
  - ✓ elevator of the upper eyelid
  - ✓ superior and inferior tarsal muscles
  - ✓ orbital muscle
  - ✓ four recti muscles – annular tendon
    - ➢ superior rectus
    - ➢ inferior rectus
    - ➢ lateral rectus
    - ➢ medial rectus
  - ✓ two obliqui muscles
    - ➢ obliquus superior
    - ➢ obliquus inferior

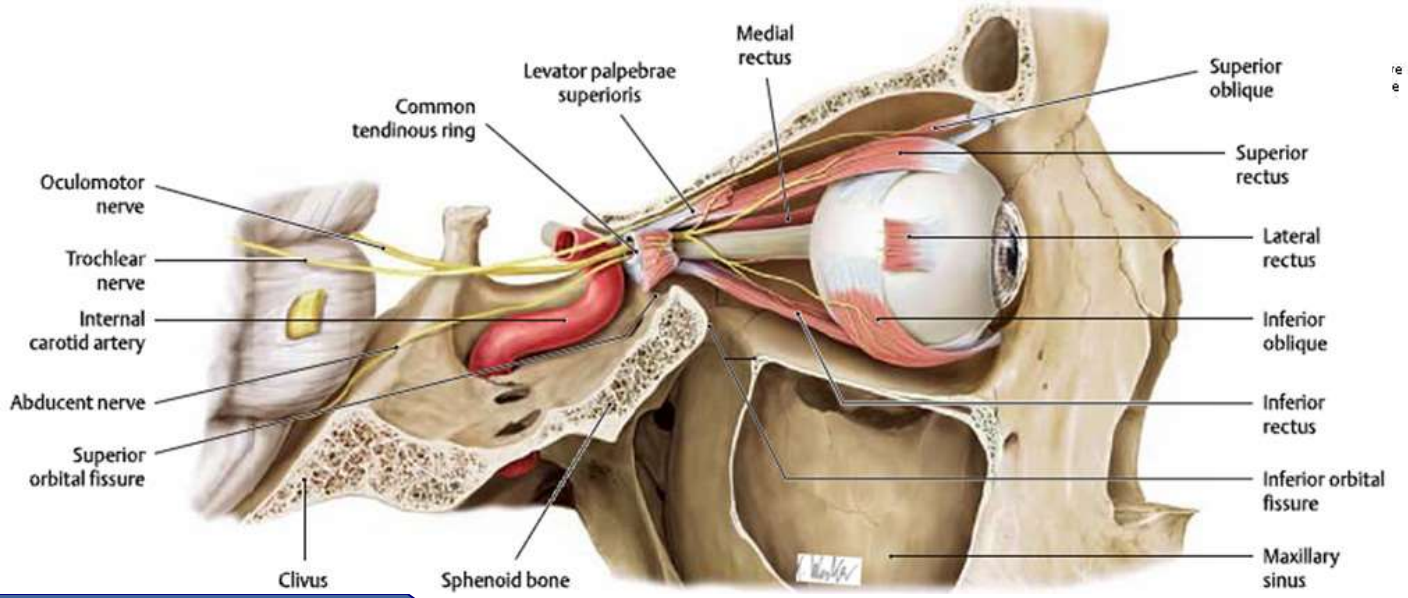




Extraocular muscles

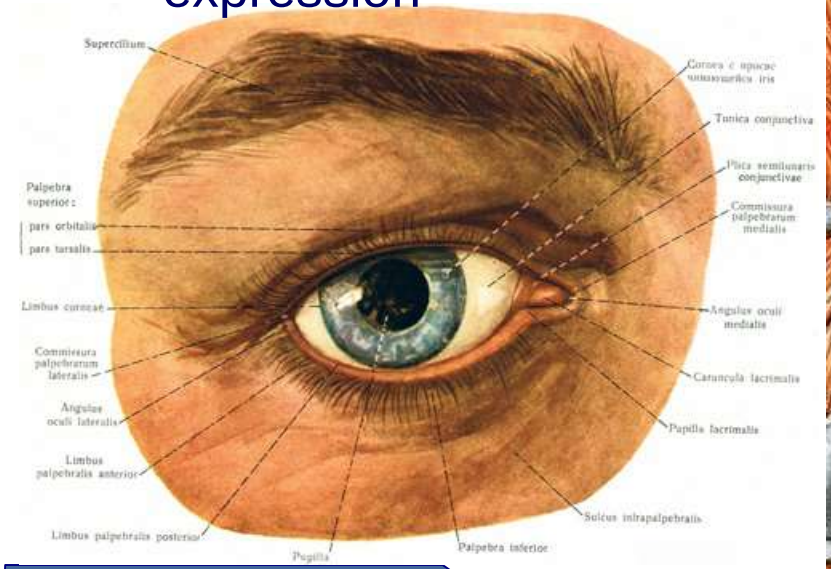
- innervation – optomotor nerves:
  - ✓ oculomotor nerve
    - ➢ *m. levator palpebrae superioris*
    - ➢ *m. rectus superior*
    - ➢ *mm. rectus inferior et medialis*
    - ➢ *m. obliquus inferior*
  - ✓ trochlear nerve ⇨ *obliquus superior*
  - ✓ abducent nerve ⇨ *rectus lateralis*

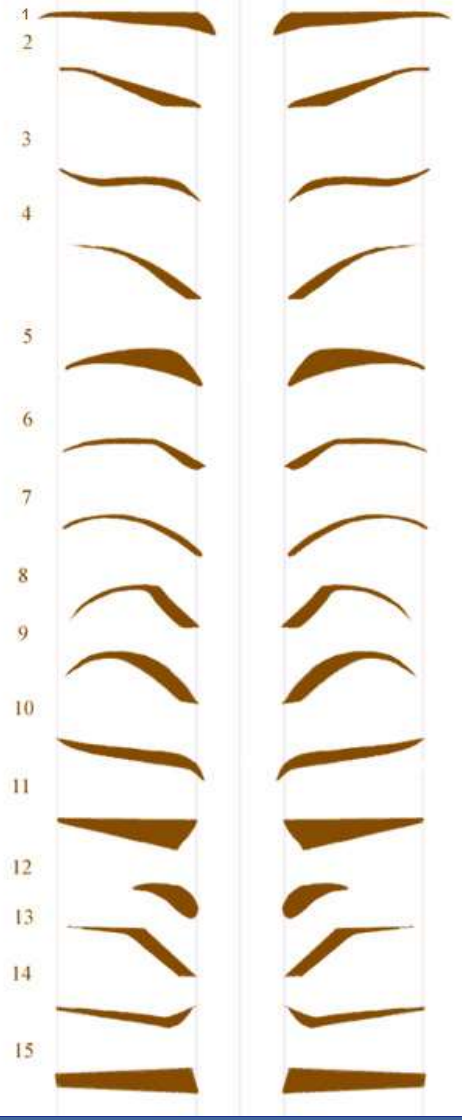




Eyebrows

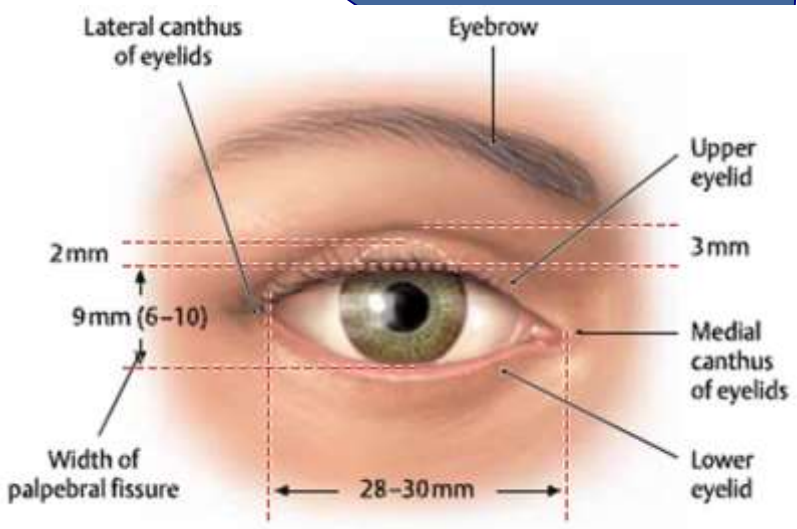
- eyebrows:
  - ✓ two arched eminences of skin
  - ✓ numerous short, thick hairs
  - ✓ fibers of orbicularis oculi, corrugator and frontal belly of occipitofrontalis muscles
- functions:
  - ✓ protect the eye – prevent moisture, mostly salty sweat and rain, from flowing into the eye
  - ✓ important to human communication and facial expression

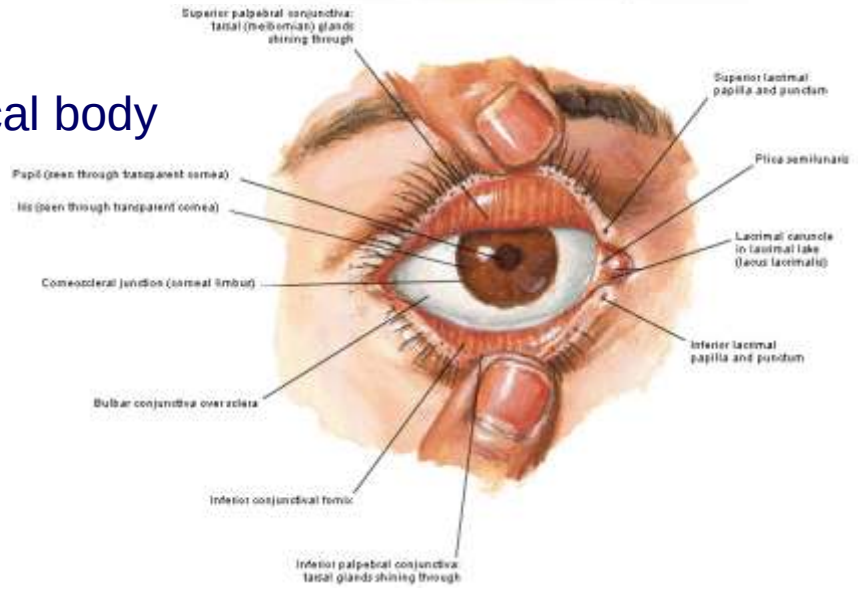




Eyelids

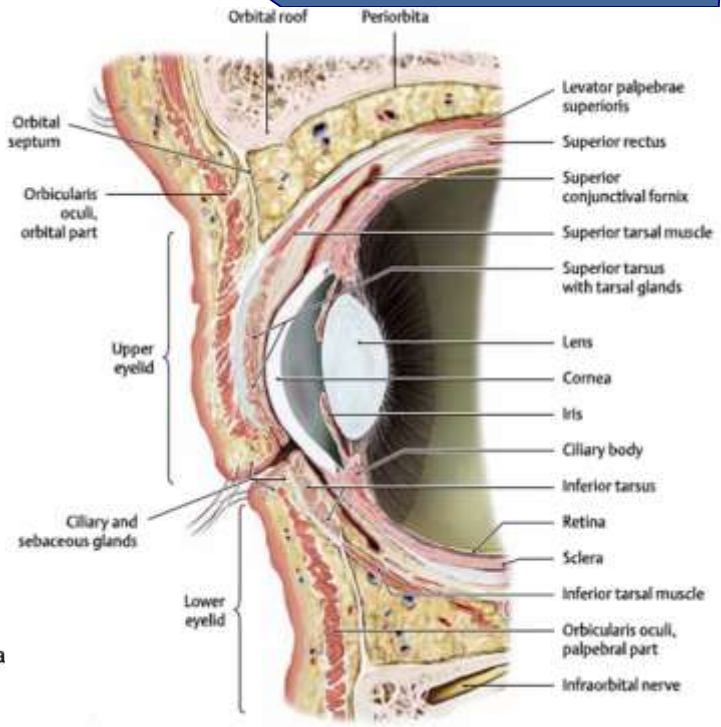
- eyelids, *palpebrae:*
  - ✓ thin, movable folds that covers and protects eyes
  - ✓ upper eylid is larger and more movable
  - ✓ palpebral fissure
  - ✓ lateral angle of the eye (lateral canthus)
  - ✓ medial angle (medial canthus)
  - ✓ *lacus lacrimalis*
  - ✓ lacrimal caruncle – small, reddish, conical body
  - ✓ lacrimal papilla (superior and inferior)
  - ✓ *punctum lacrimale*
  - ✓ eyelashes – short, thick curved hairs
  - ✓ ciliary glands (of *Moll*)
  - ✓ *Meibomian* (tarsal) glands

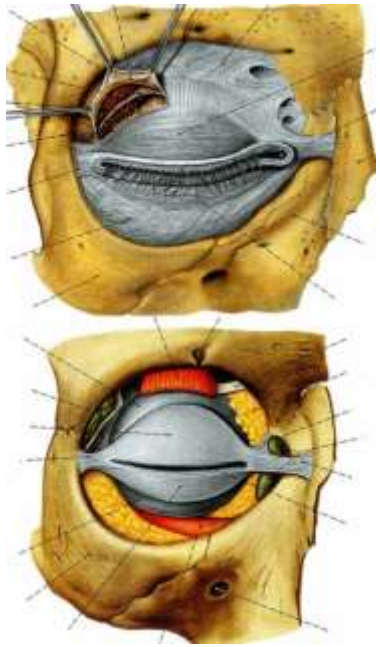


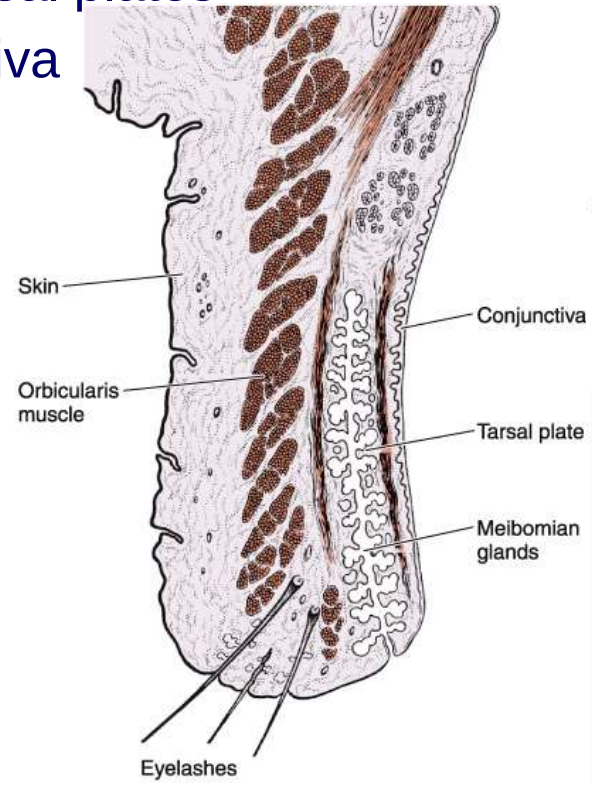


Eyelids

- composition – several layers:
  - ✓ skin
  - ✓ subcutaneous tissue
  - ✓ orbicularis oculi
  - ✓ orbital septum&tarsal plates
  - ✓ palpebral conjunctiva



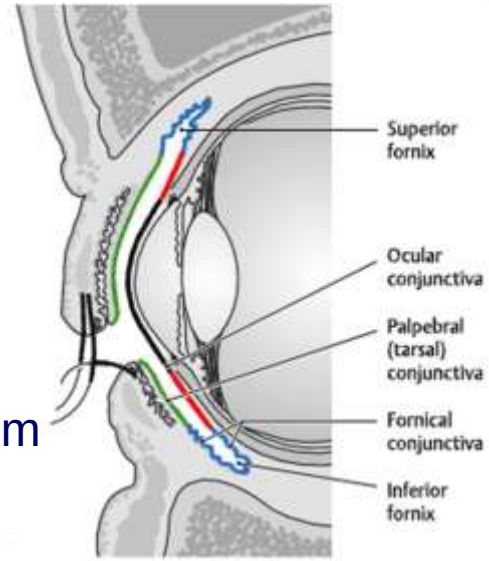




Conjunctiva

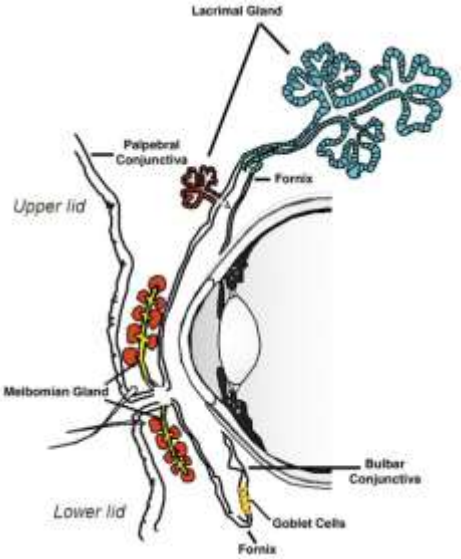
- conjunctiva:
  - transparent mucous membrane
  - consisting of cells and underlying basement membrane
  - over the inner surface of the eyelids
  - over the front part of the sclera and cornea

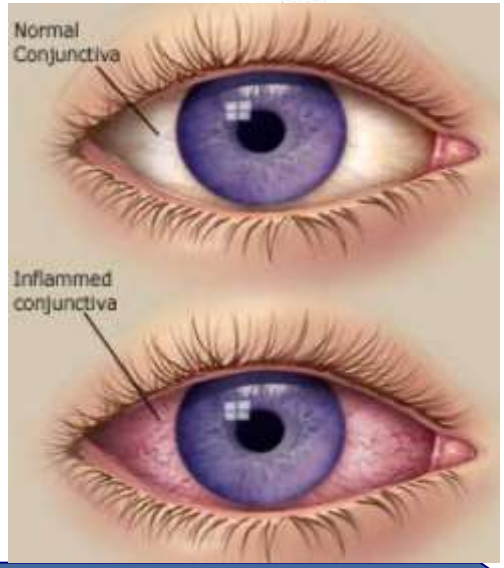
- ✓ palpebral conjunctiva
  - highly vascular
  - adherent to the tarsi
  - conjunctival fornix
- ✓ ocular conjunctiva
  - thin, transparent
  - loosely connected to the eyelid
  - continues as the corneal epithelium
- ✓ semilunar fold of conjunctiva



Conjunctiva

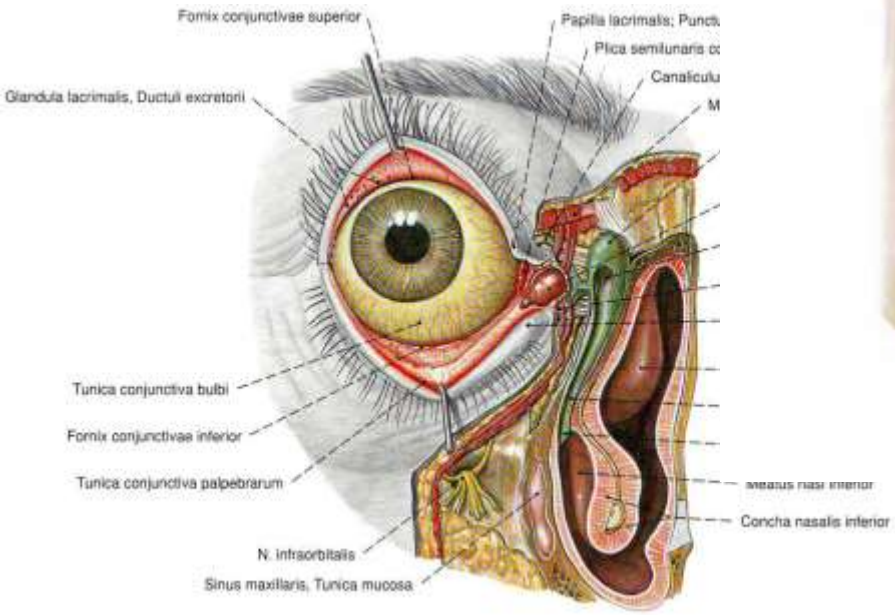
- functions:
  - ✓ contributes to immune surveillance
  - ✓ helps lubricate the eye by producing mucus and tears
  - ✓ helps to prevent the entrance of microbes into the eye
- conjunctival reflex:
  - ✓ closure of the eyelid when the conjunctiva is touched

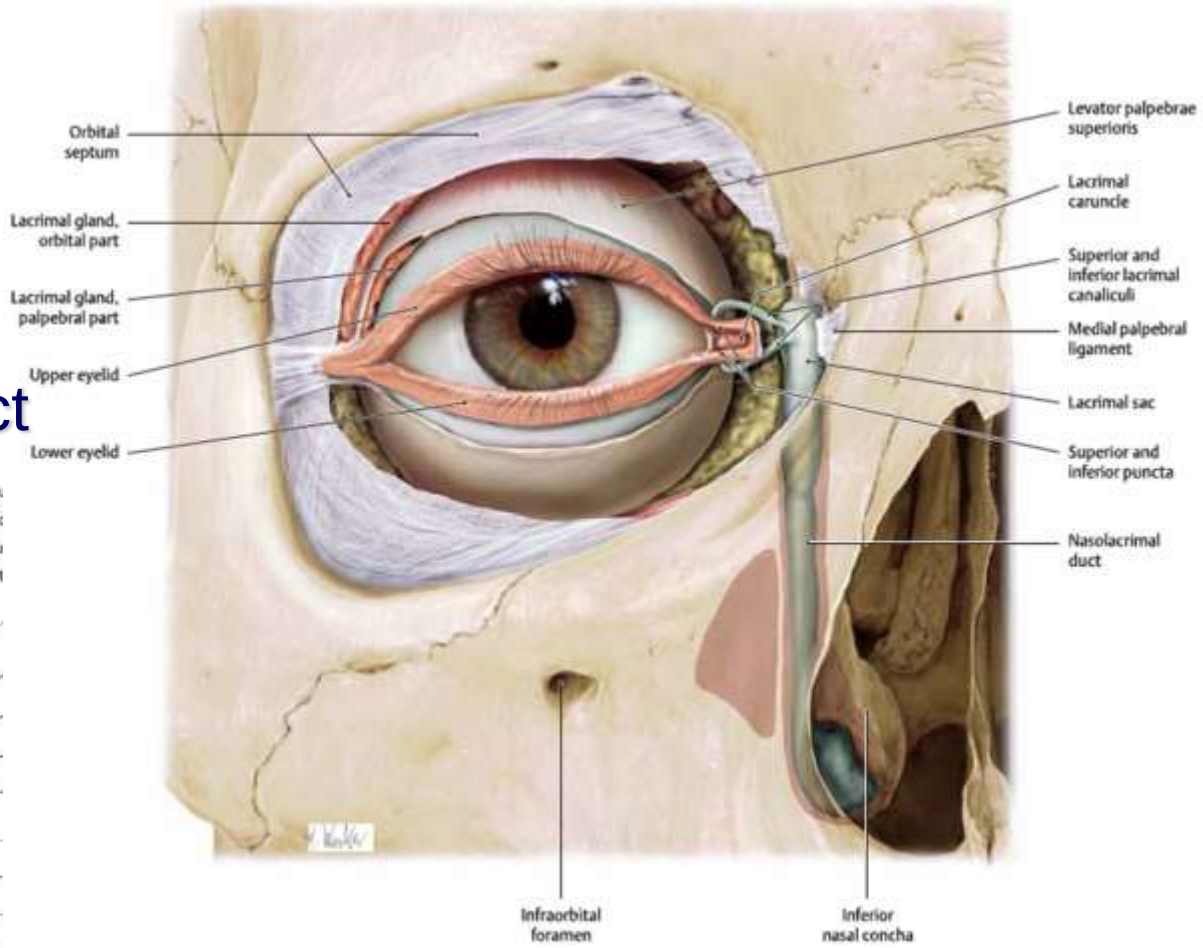




Human lacrimal apparatus

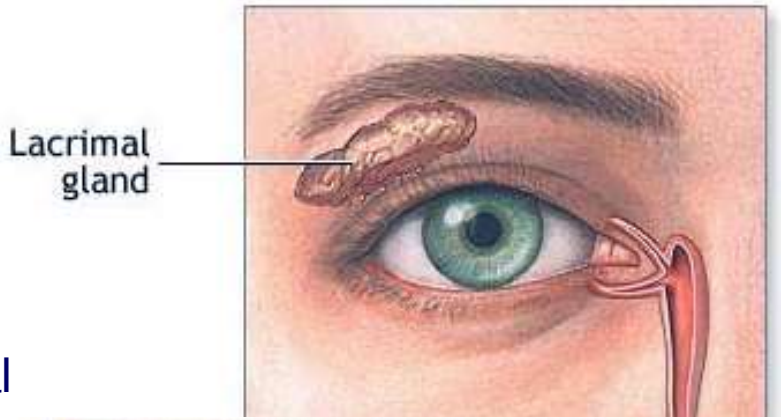
- ✓ lacrimal gland
- ✓ lacrimal canaliculi
- ✓ lacrimal sac
- ✓ nasolacrimal (tear) duct

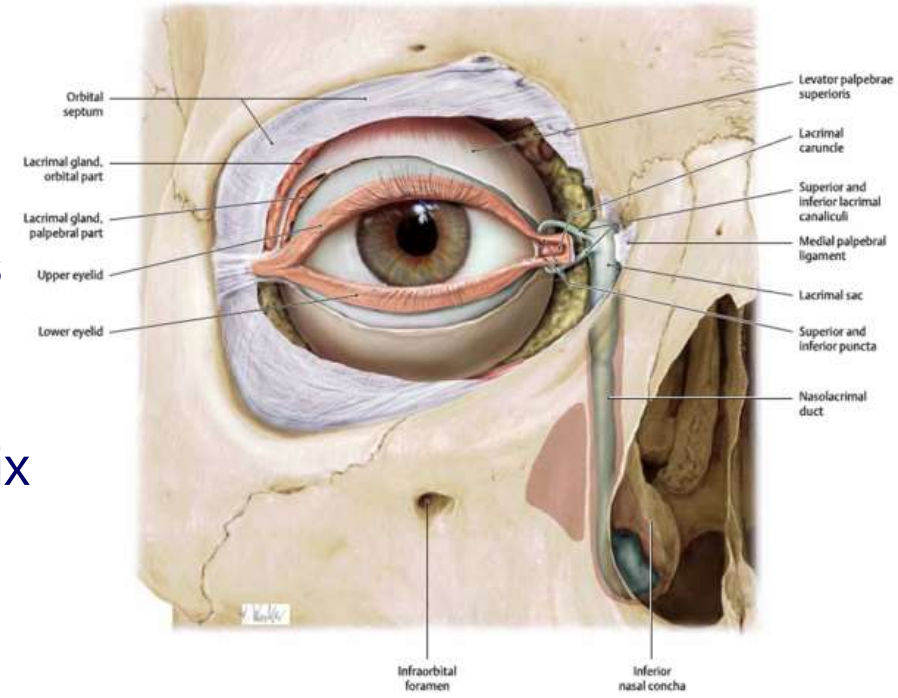




Lacrimal gland

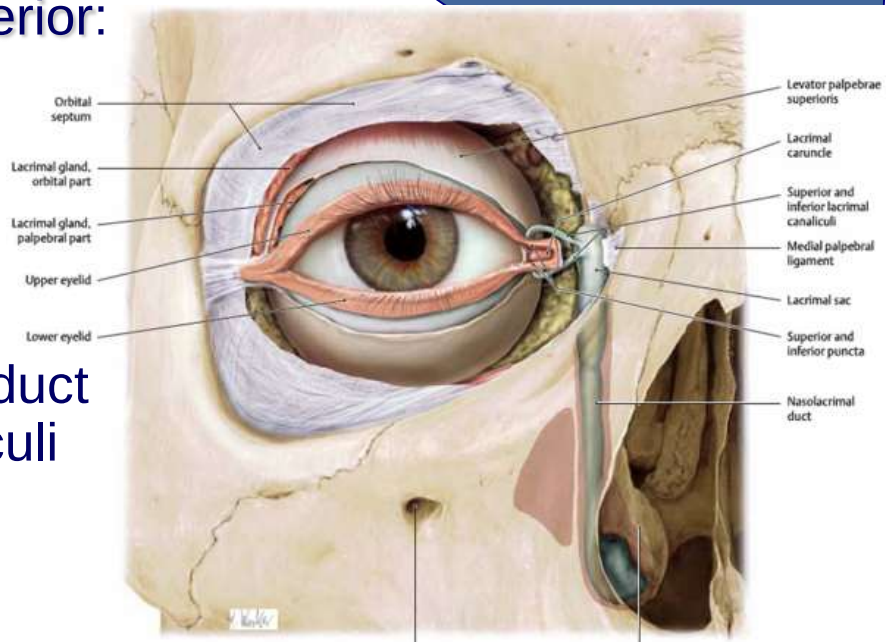
- almond-like, two parts by the aponeurosis of the levator palpebrae superioris muscle:
  - ✓ larger upper **orbital part** – in *fossa lacrimalis*
  - ✓ smaller lower **palpebral part**, ⅓ of the orbital
  - ✓ small **accessory lacrimal glands**
    - ➢ more numerous in the upper lid
    - ➢ in and near the conjunctival fornices
  - ✓ ~12 ducts
    - ⇨ into the superior conjunctival fornix
  - ✓ secretes a complex fluid, the tears

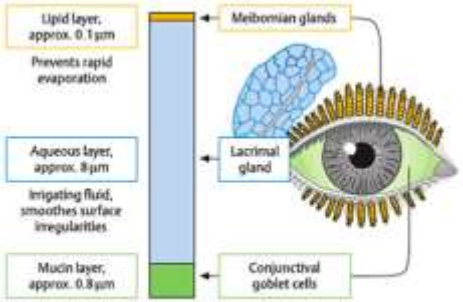




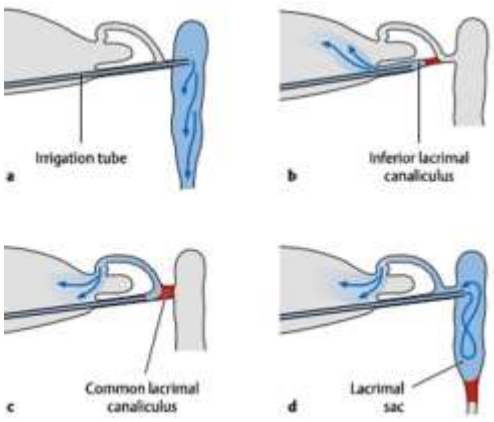
Lacrimal pathways

- lacrimal canaliculi – superior and inferior:
  - ✓ ~10 mm in length
  - ✓ dilated into *ampullae*
  - ✓ commence at the *puncta lacrimalia*
- lacrimal sac:
  - ✓ upper blind end of the nasolacrimal duct ⇨ connect it with the lacrimal canaliculi
  - ✓ ~12 mm in length, lodged in a fossa
- nasolacrimal (tear) duct:
  - ✓ membranous canal; ~18 mm long
  - ✓ drains into the inferior nasal meatus





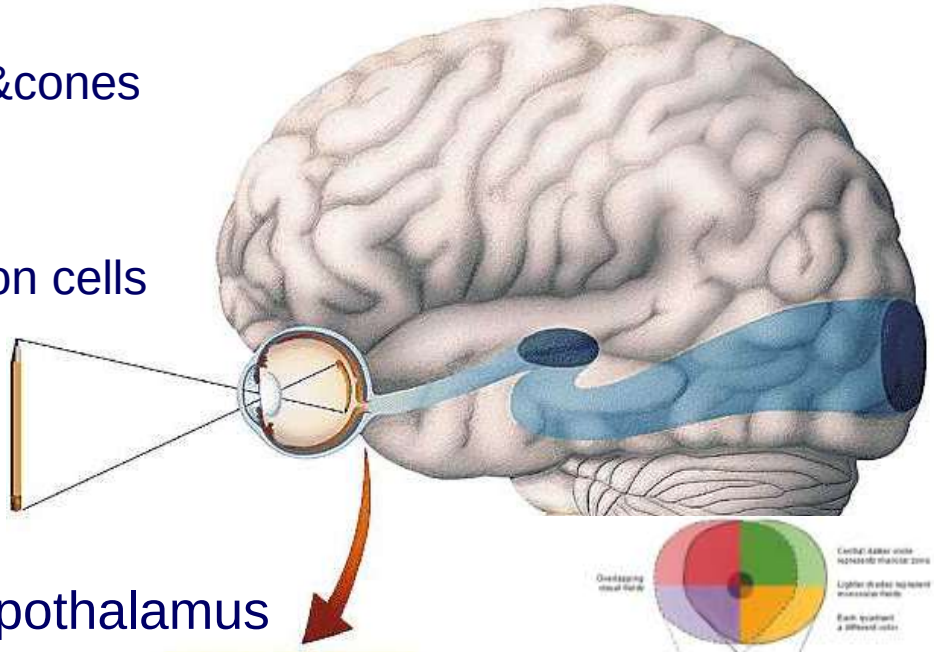
Structure of the tear film

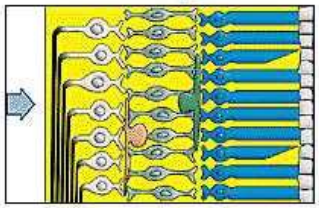


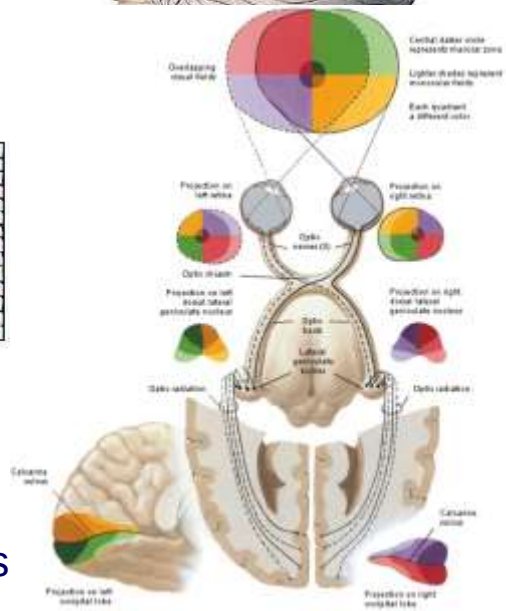
Obstruction of the lacrimal drainage

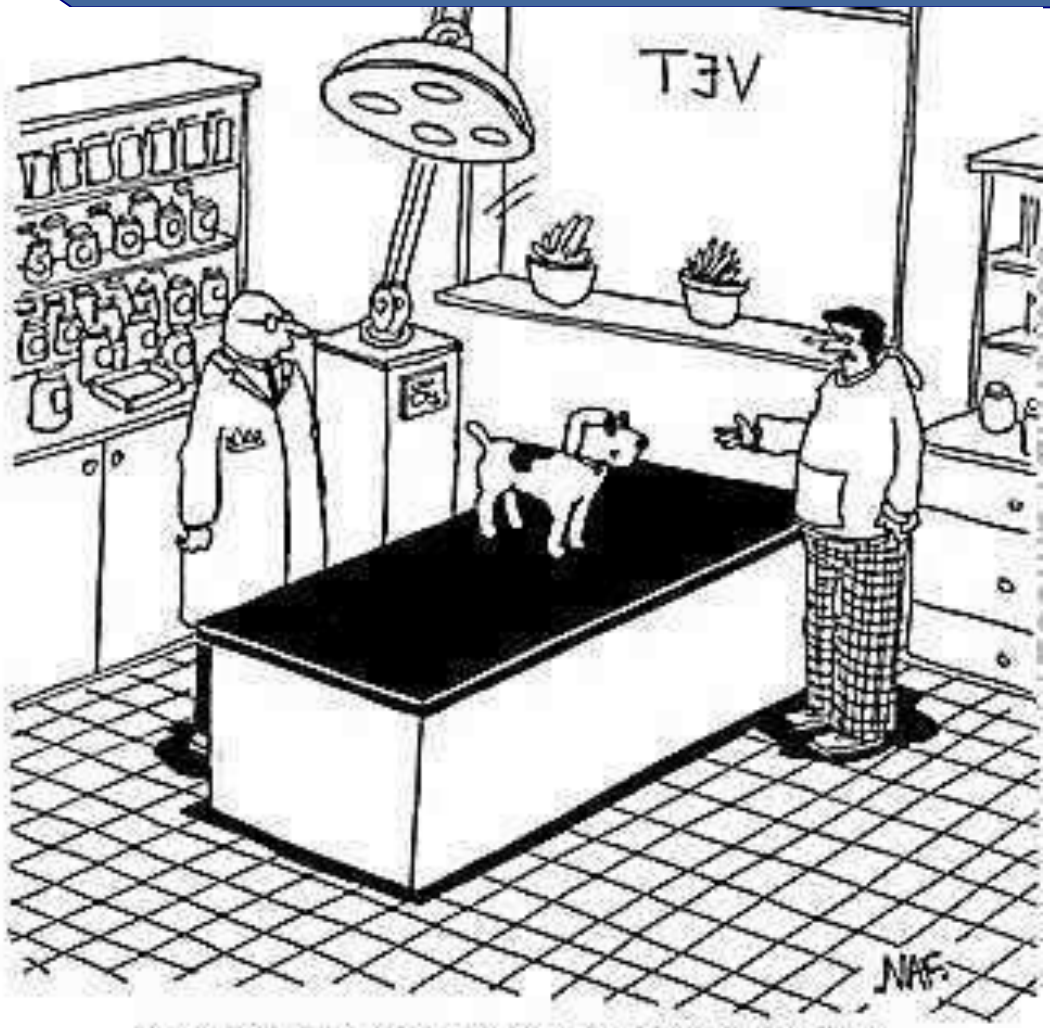
Visual pathway

- retina:
  - ✓ Ist neuron: photoreceptor cells – rods&cones
  - ✓ IInd neuron: bipolar cells
  - ✓ IIIrd neuron: retinal ganglion cells
- optic nerve – 1 million axons of ganglion cells
- optic tract:
  - ➢ superior colliculus
  - ➢ pretectal area
  - ➢ mesencephalic tegmentum
  - ➢ suprachiasmatic nucleus of the hypothalamus
- lateral geniculate body – IVth neuron
  - ➢ geniculocalcarine tract ⇨ optic radiation (of *Gratiolet*)
- striate cortex (area 17), primary visual cortex (V-I):
  - ✓ 3% of cerebral surface area
  - ✓ 10% of cortical neurons – numerous GABAergic interneurons

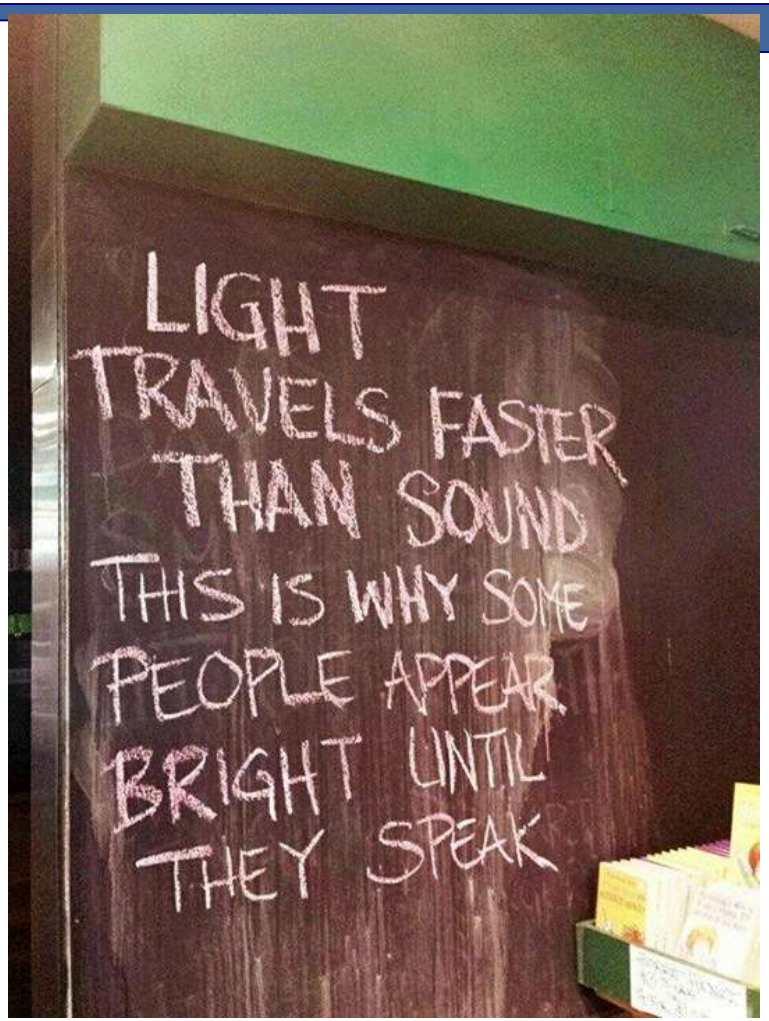








"When I asked you to remove his balls I didn't mean his eye balls!"



Thank you...