Visual Neuroscience

Structure and Function of the Eye

(adapted and updated from Merrick Moseley and Michael Gresty)

Richard Cheong-Leen

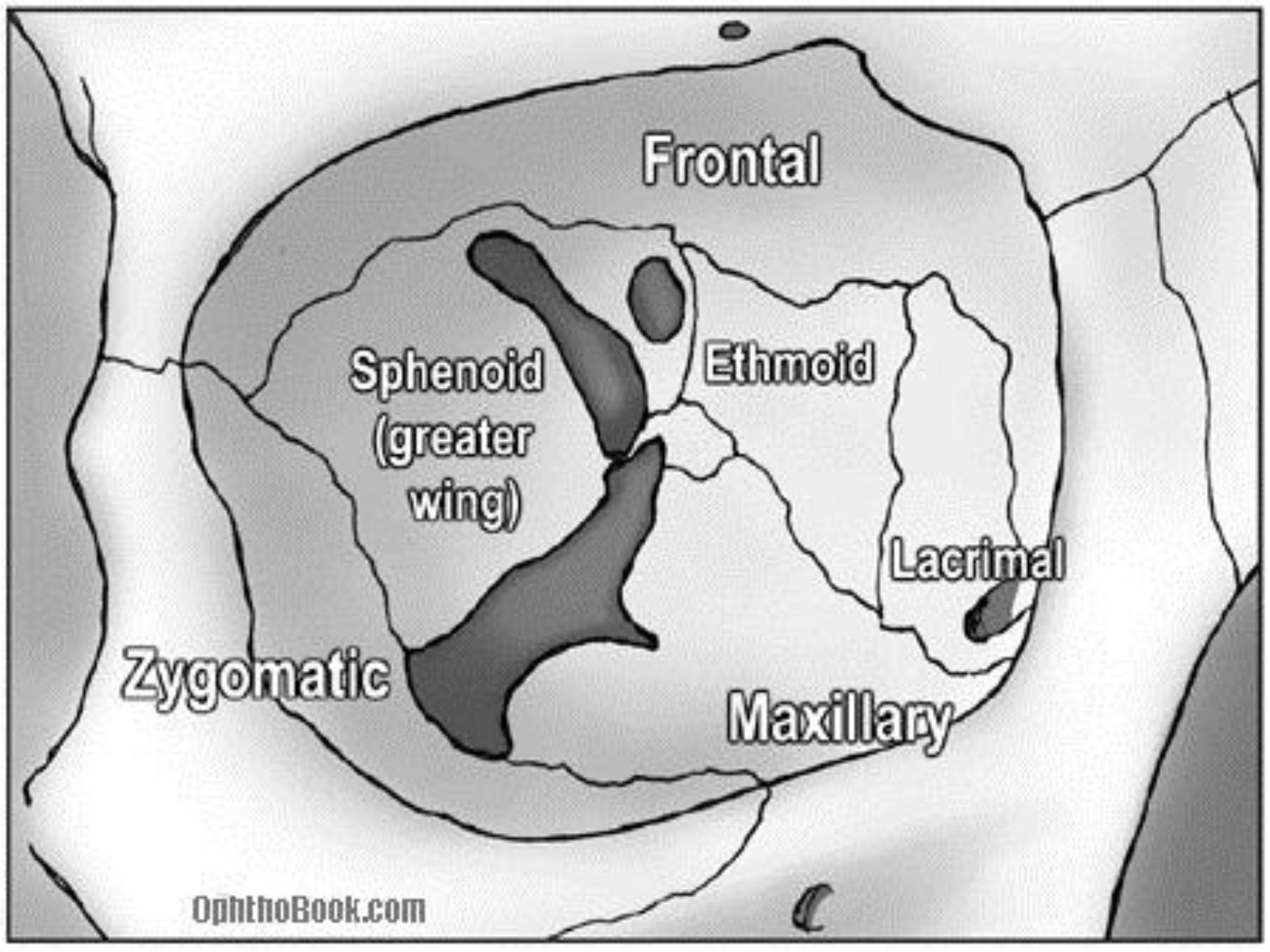
r.cheong-leen@imperial.ac.uk

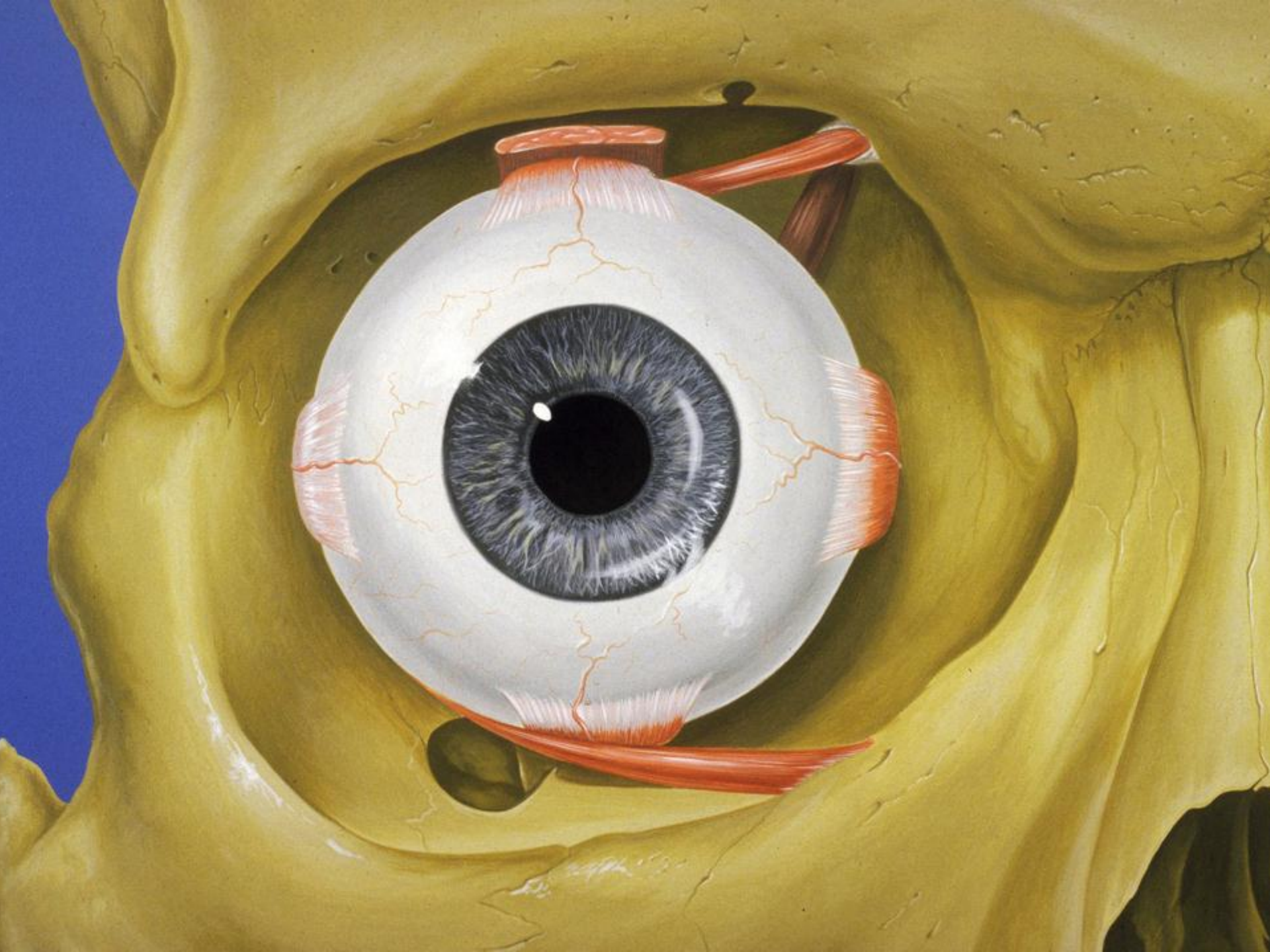
(Division of Neuroscience, Department of Medicine Imperial College/Western Eye Hospital)

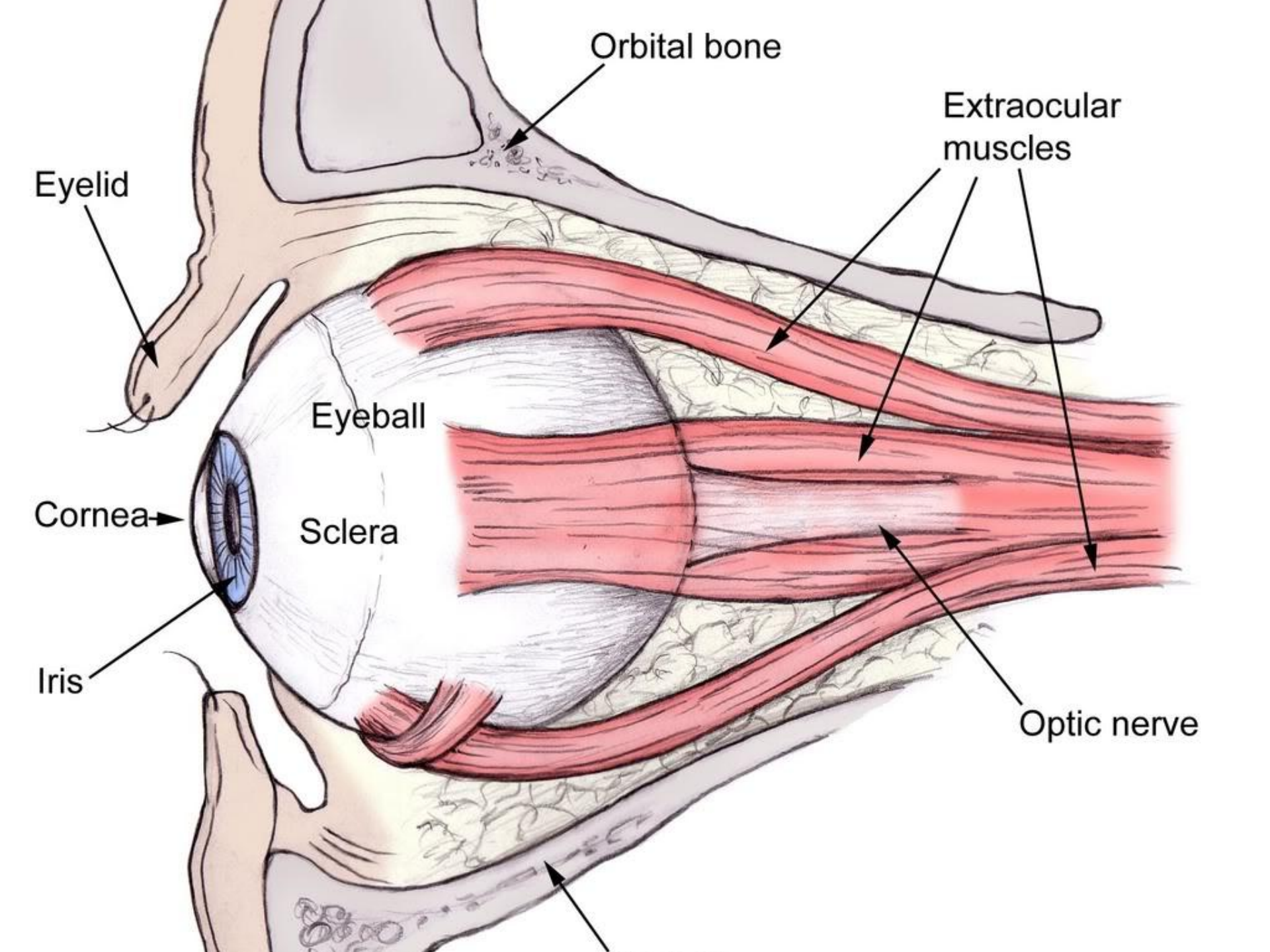
Part I Eye Protection

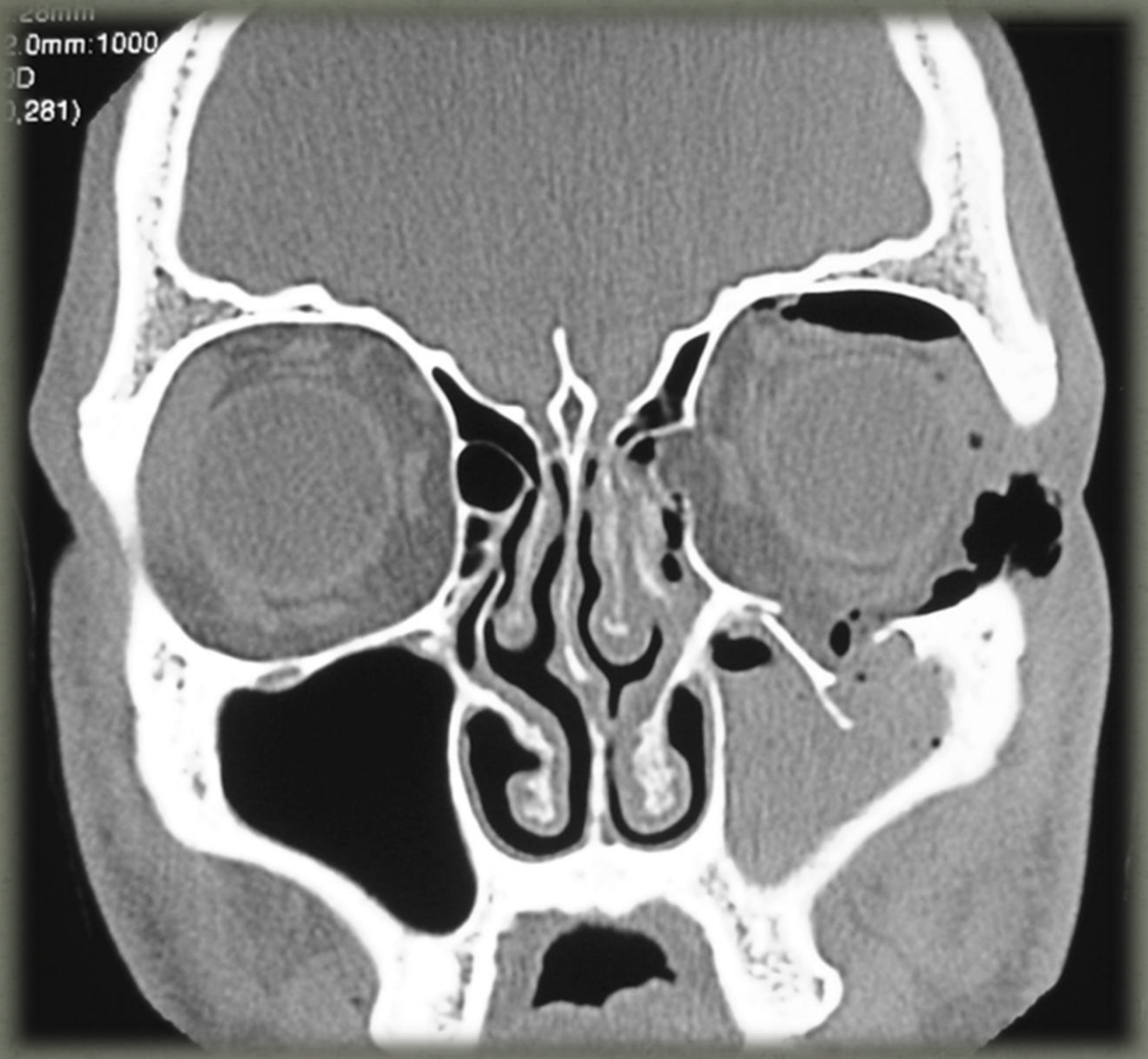
Adnexal - Orbit

- Protection
- Bony Confined Pyramid Space
- Globe suspended within orbit fat by ligament
- Contains vital structure, nerves, blood vessels, eye muscles


Frontal
Sphenoid (greater wing)
Ethmoid
Lacrimal
Zygomatic
Maxillary
OphthoBook.com




Orbital bone
Extraocular muscles
Eyelid
Eyeball
Cornea
Sclera
Iris
Optic nerve



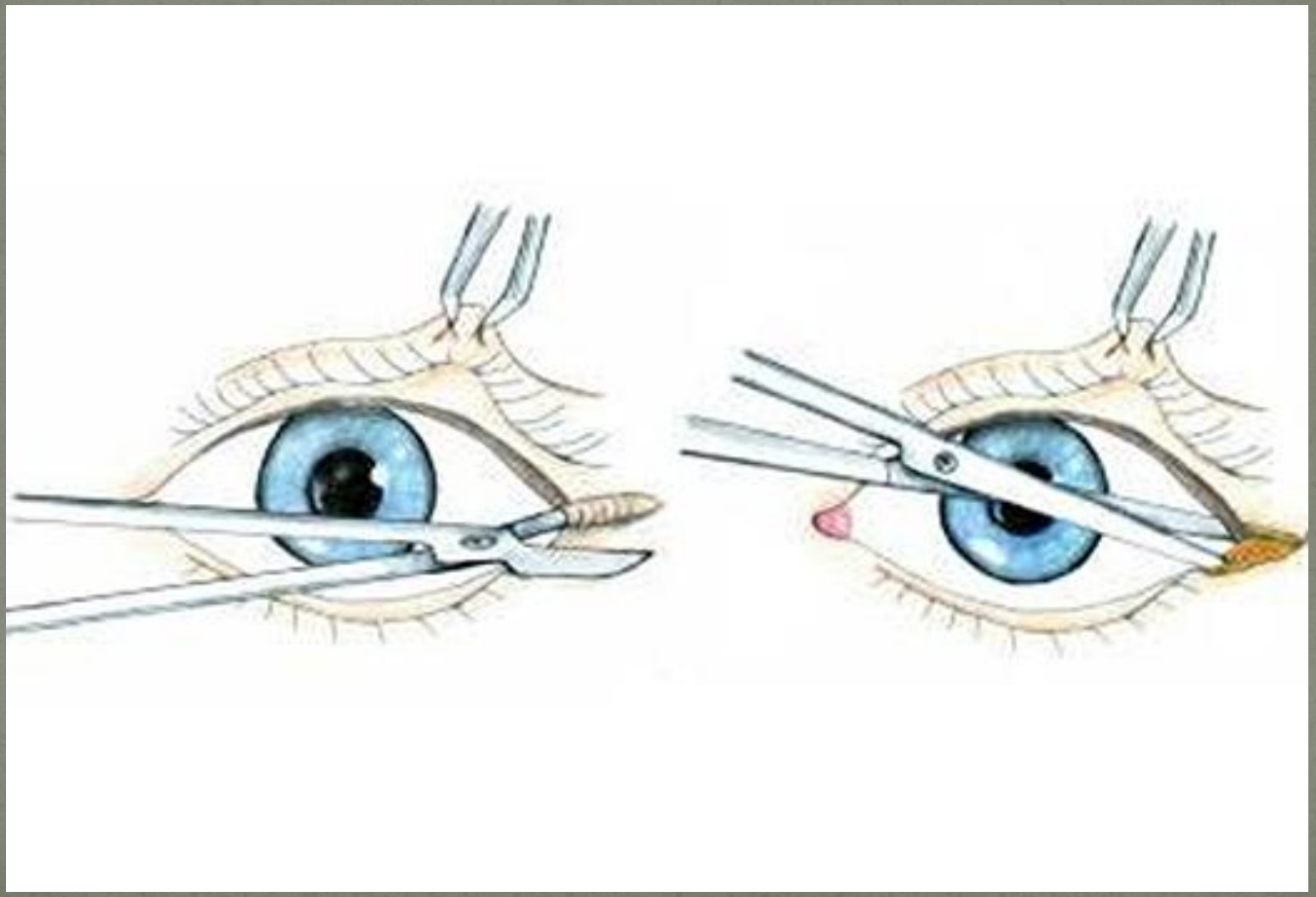
Blow Out Fracture

Medial and Inferior Wall are the weakest

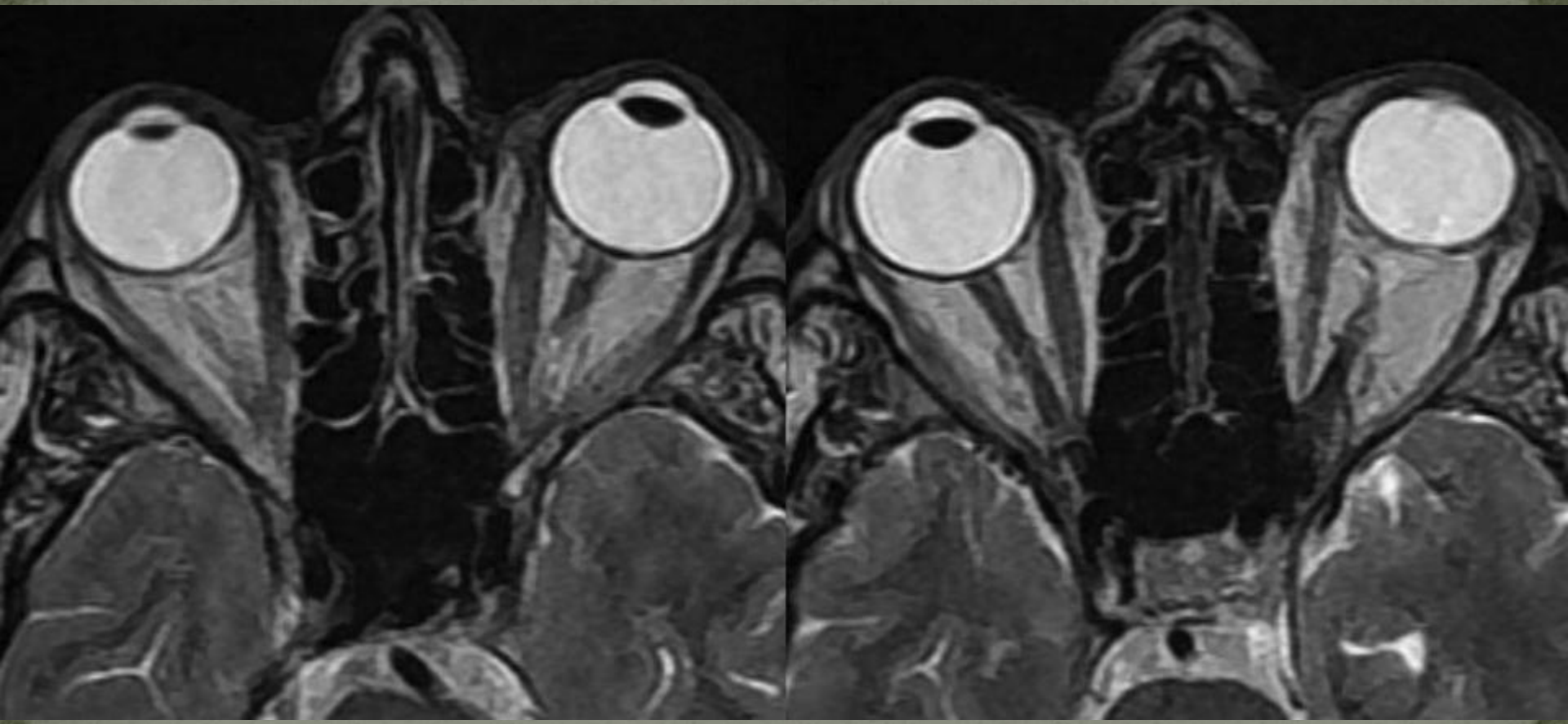
Gun Shot Wound with Orbital Haemorrhage

Bony casing makes orbit susceptible to compartment syndrome in the presence of orbital haemorrhage.

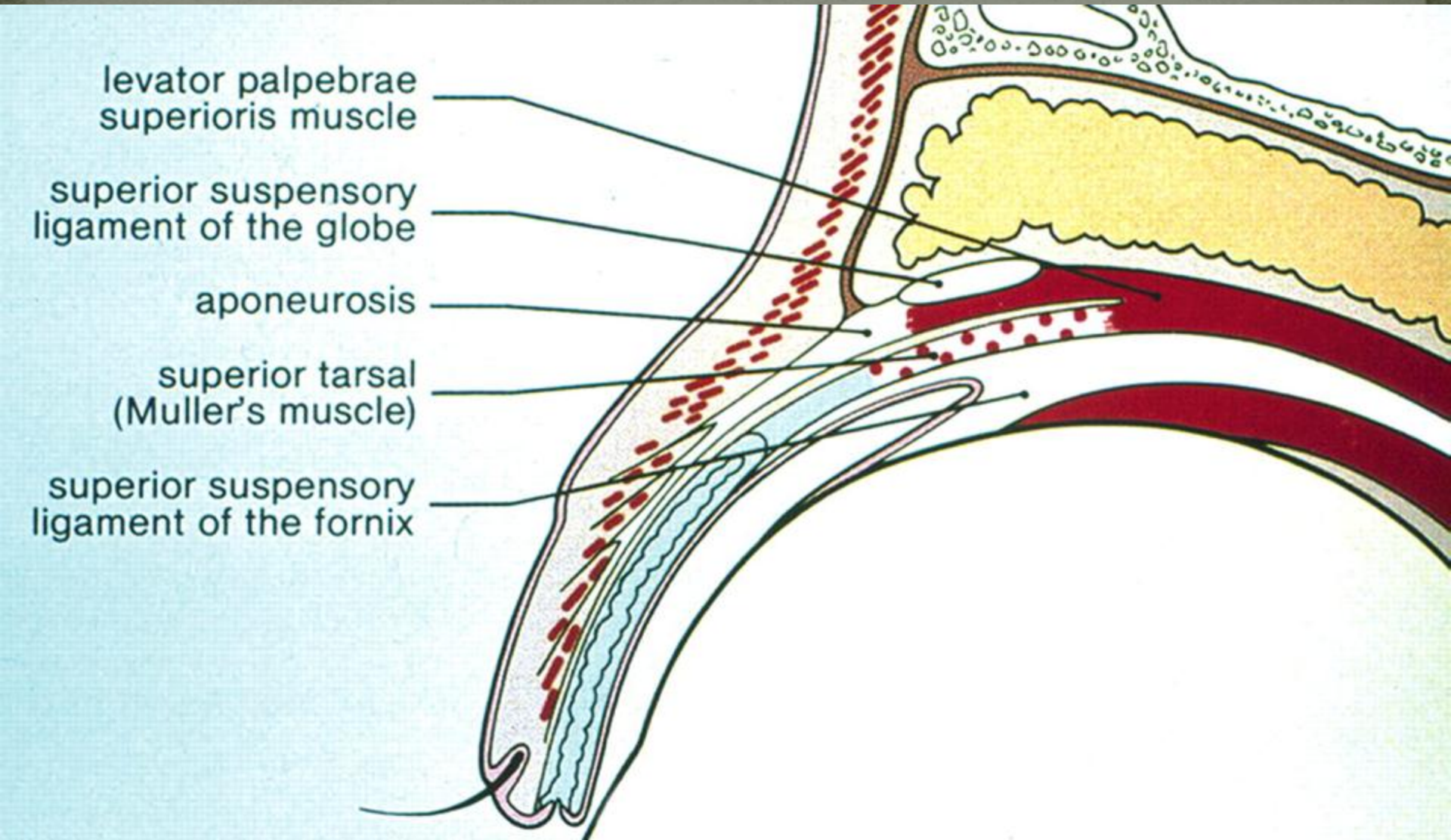
Lateral Canthotomy to release pressure



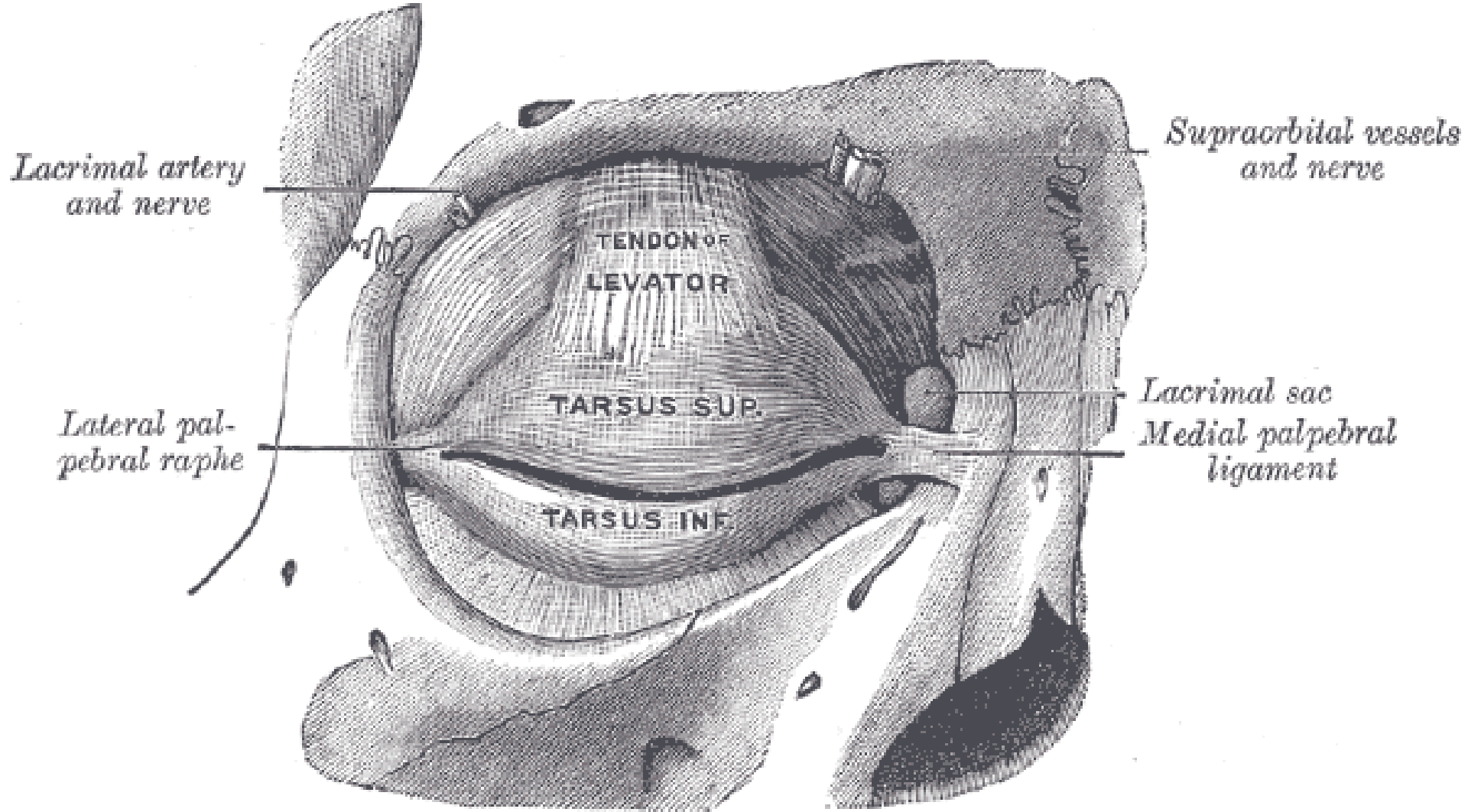
Thyroid Eye Disease



Adnexal - Lid

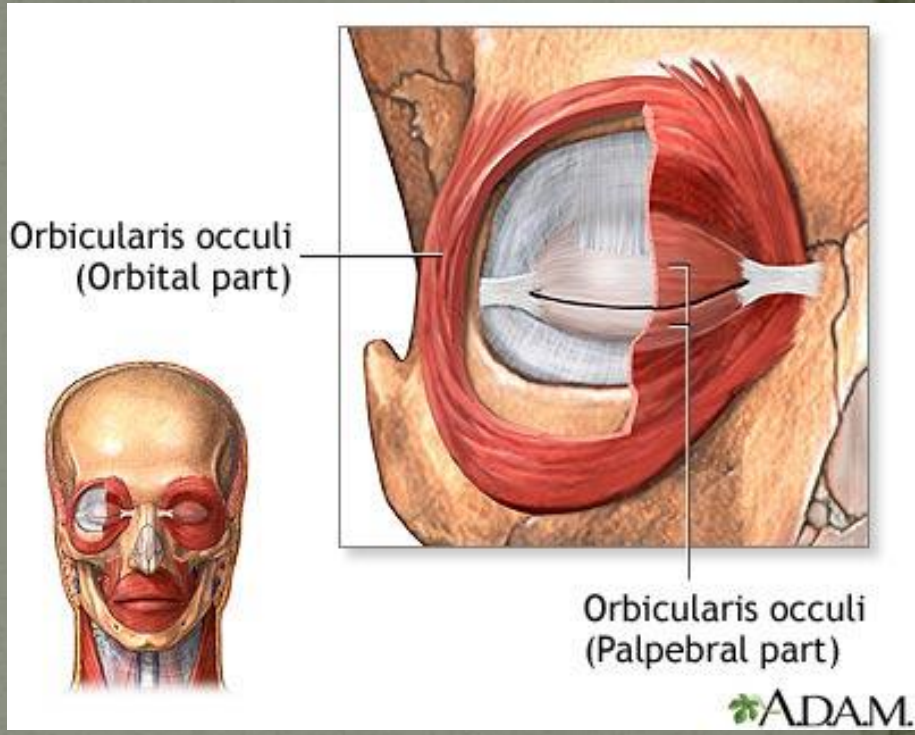

levator palpebrae superioris muscle
superior suspensory ligament of the globe
aponeurosis
superior tarsal (Muller's muscle)
superior suspensory ligament of the fornix

Lid Anatomy

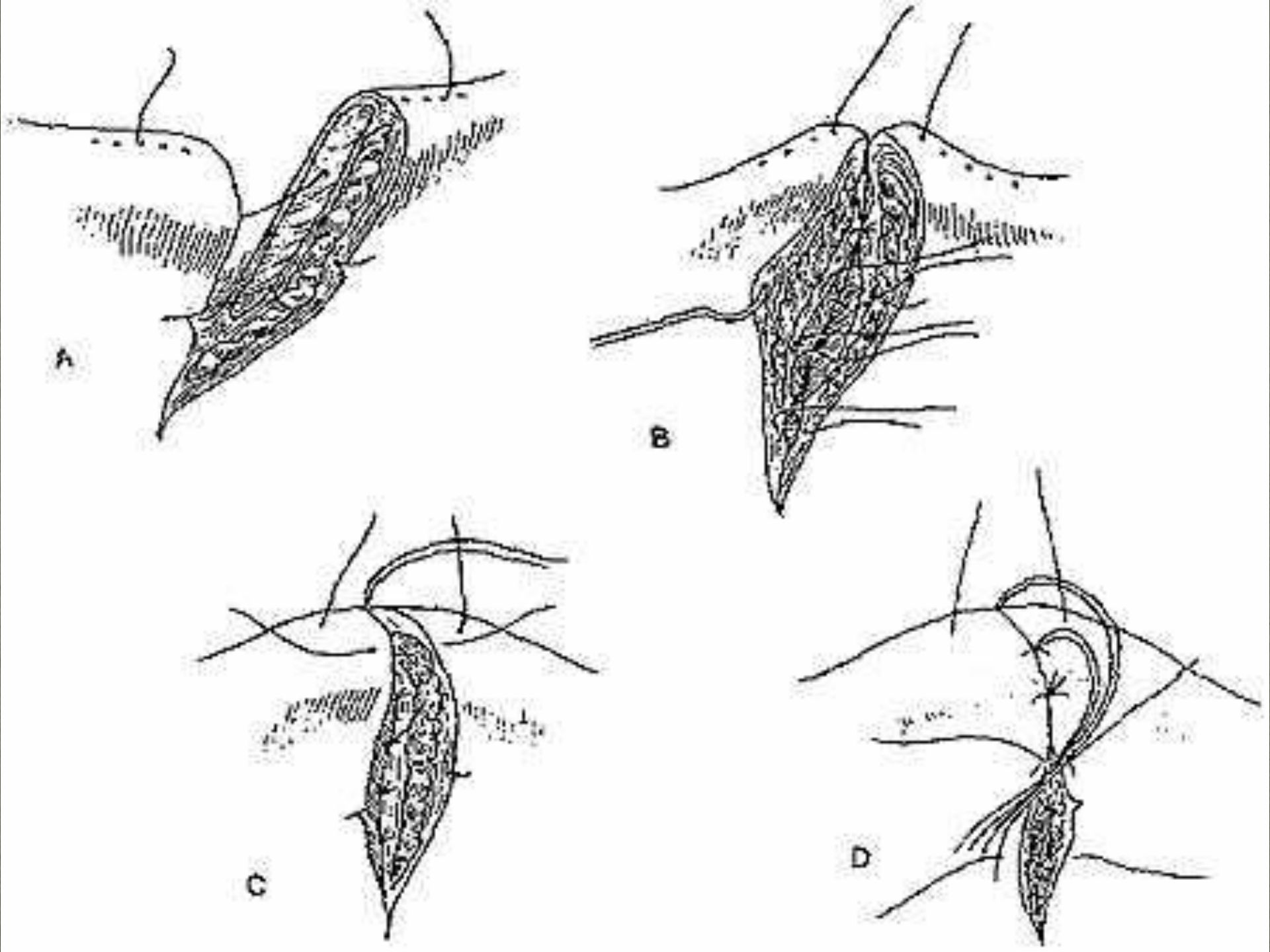

Lacrimal artery and nerve
Lateral palpebral raphe
TENDON OF LEVATOR
TARSUS SUP.
TARSUS INF.
Supraorbital vessels and nerve
Lacrimal sac
Medial palpebral ligament

Blinking

- Duration 100-400msec
- Protect from Foreign Body
- Lubrication with Tear Film
- Prevent Eye from Drying
- Removal of Irritant
- Reduced in Parkinsonism



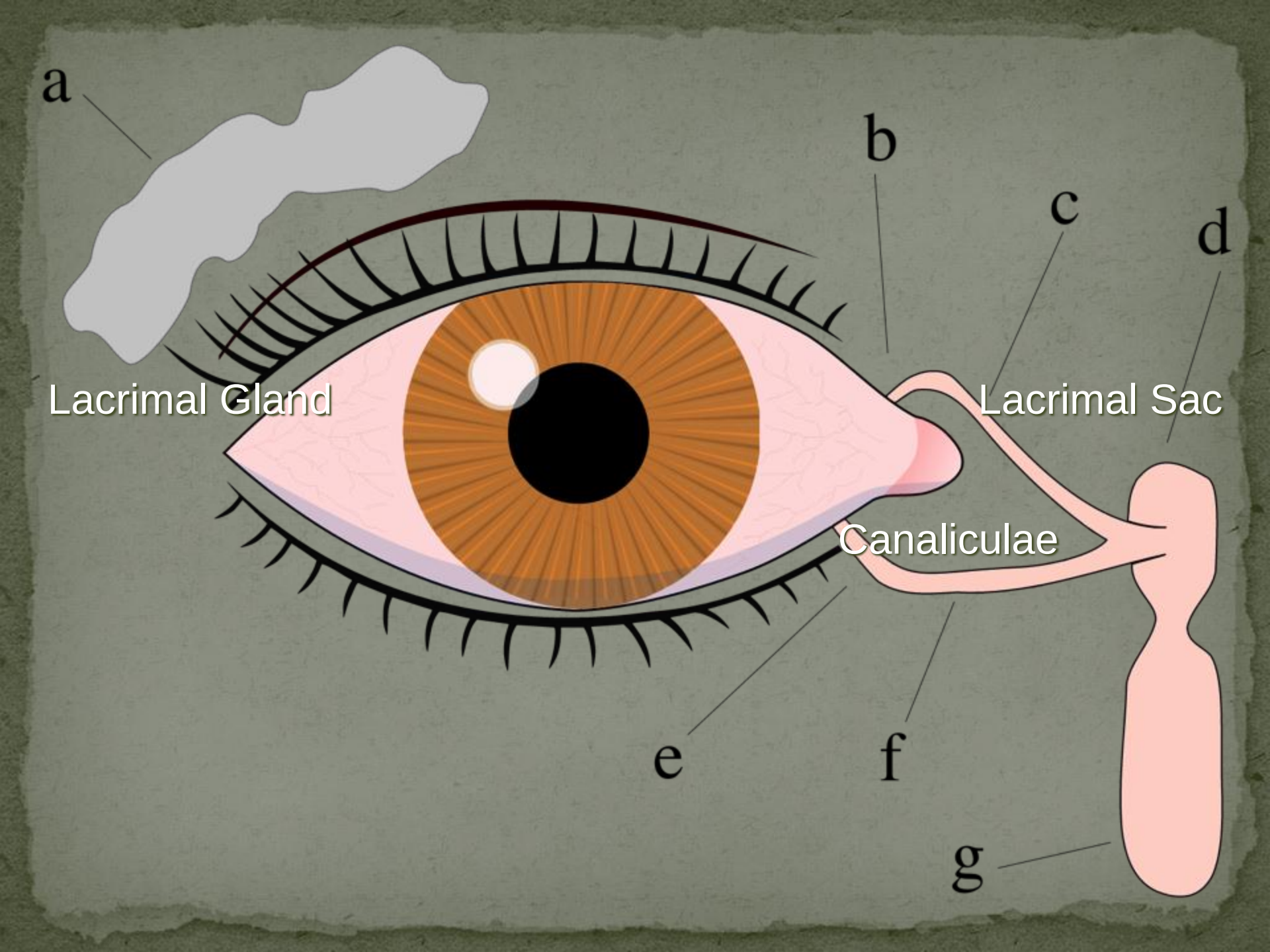

EyeRounds.org

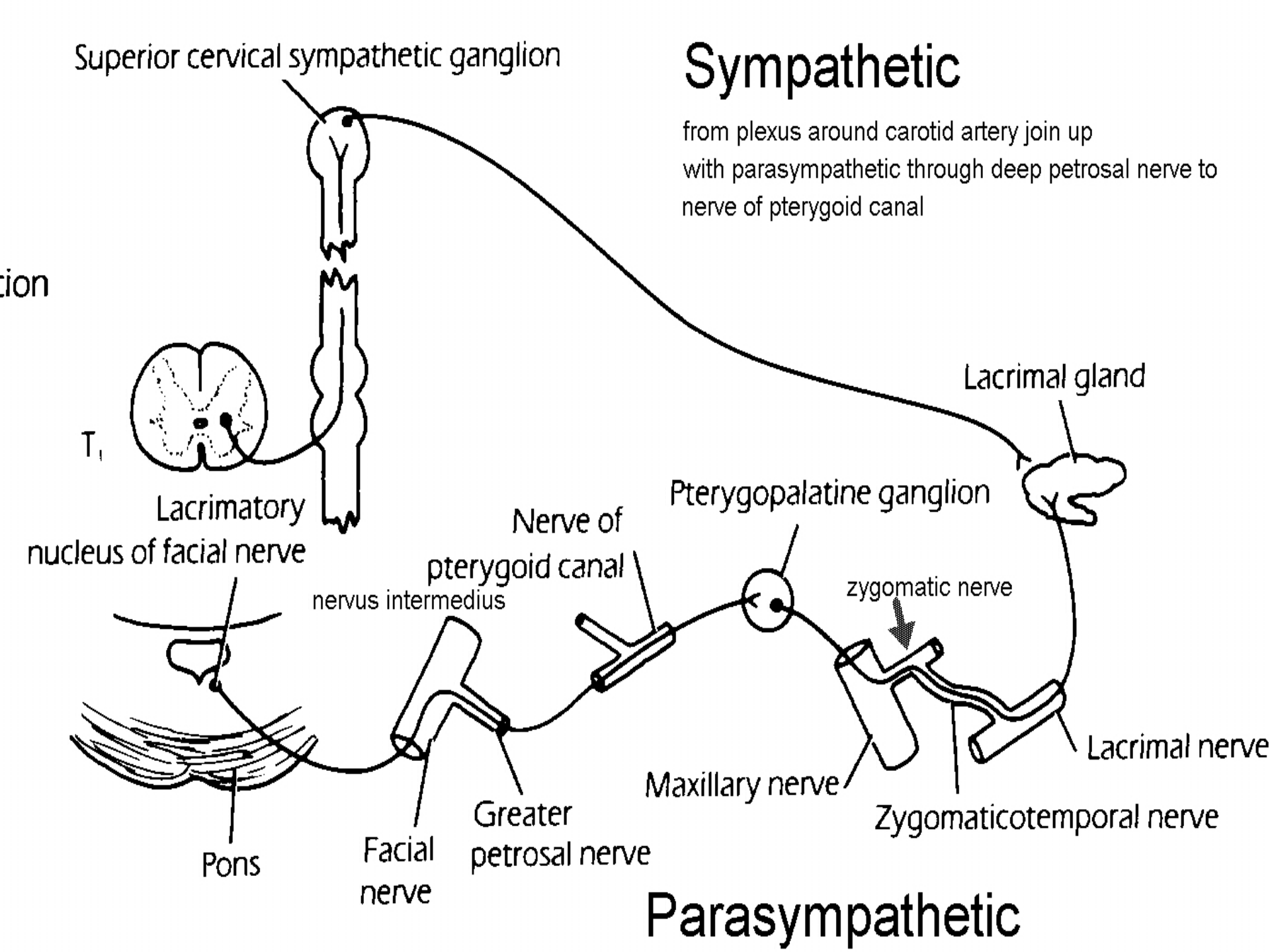

A
B
C
D

Ectropion

Adnexal – Tear Film System

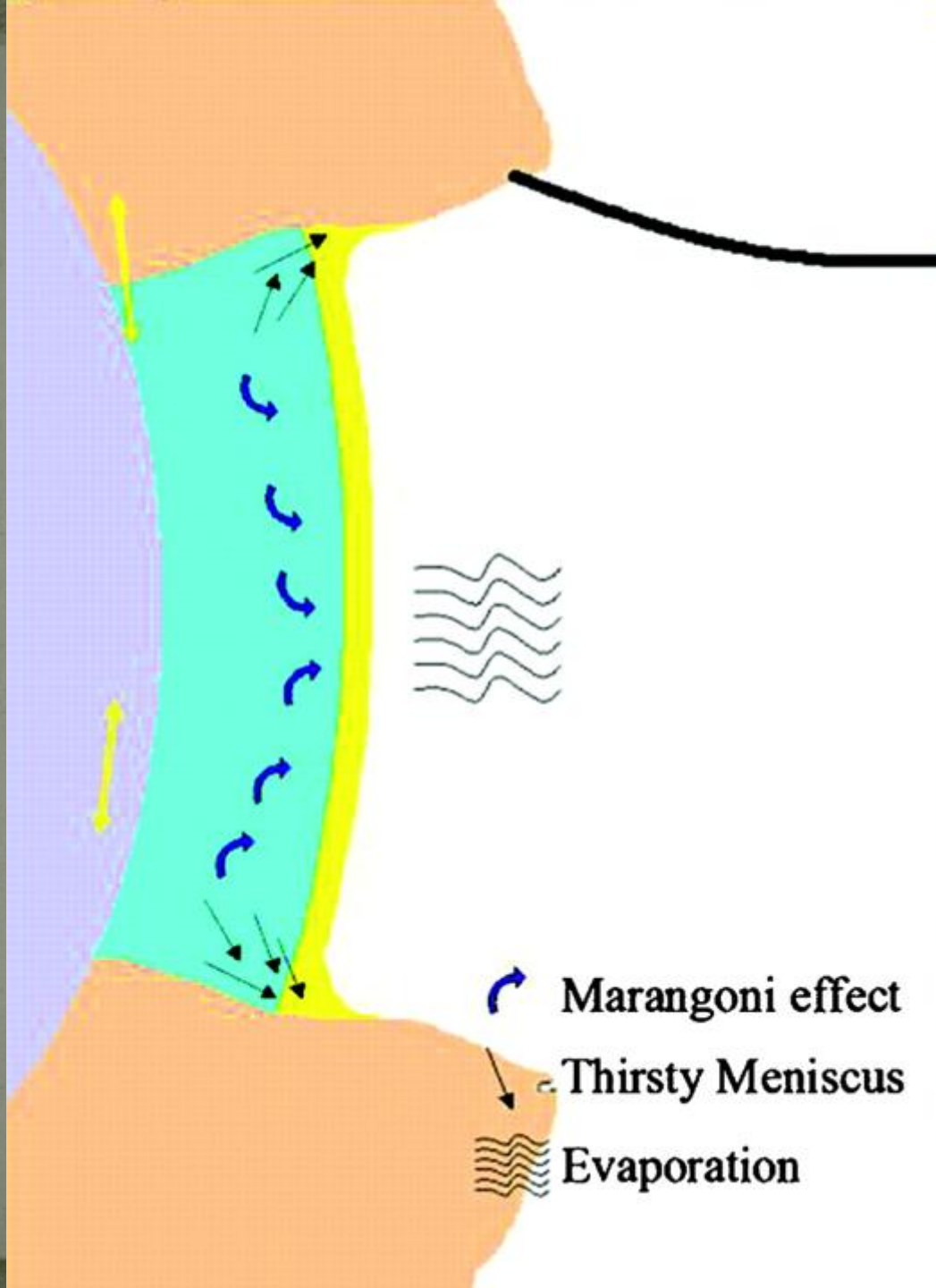
- Components
  - Nervous System Control
  - Lacrimal Gland and Lacrimal Outflow
  - Tear Film – 3 Layers

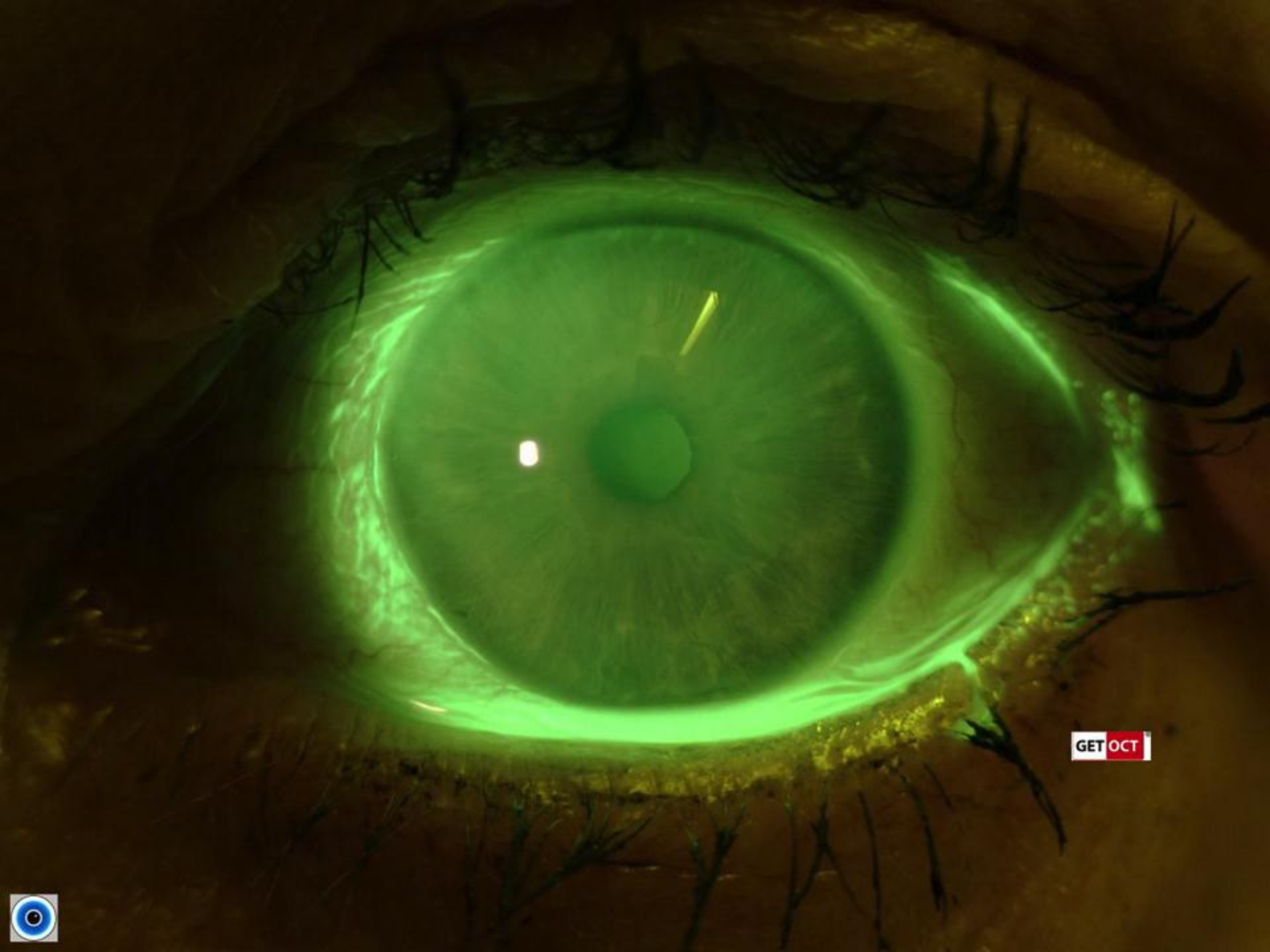

a
b
c
d
Lacrimal Gland
Lacrimal Sac
Canaliculae
e
f
g


Superior cervical sympathetic ganglion
Sympathetic
from plexus around carotid artery join up
with parasympathetic through deep petrosal nerve to
nerve of pterygoid canal
tion
T1
Lacrimal gland
Lacrimatory
nucleus of facial nerve
Pterygopalatine ganglion
Nerve of
pterygoid canal
nervus intermedius
zygomatic nerve
Lacrimal nerve
Maxillary nerve
Zygomaticotemporal nerve
Greater
petrosal nerve
Facial
nerve
Pons
Parasympathetic

Tear Film Functions

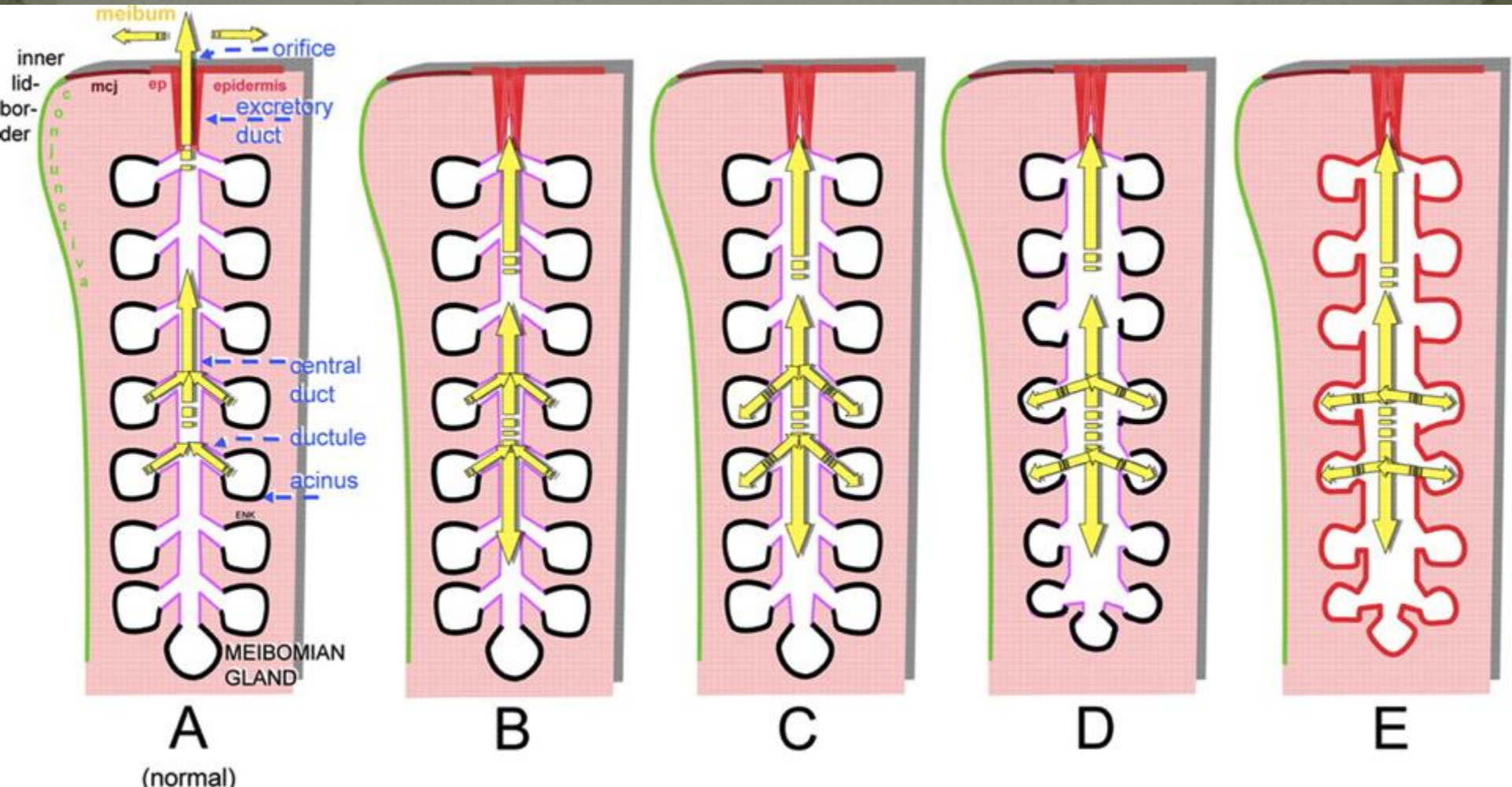
- Maintain Optically Smooth Corneal Refractive Surface
- Hydration
- Oxygen Supply to Cornea
- Removal of Debris
- Bactericide



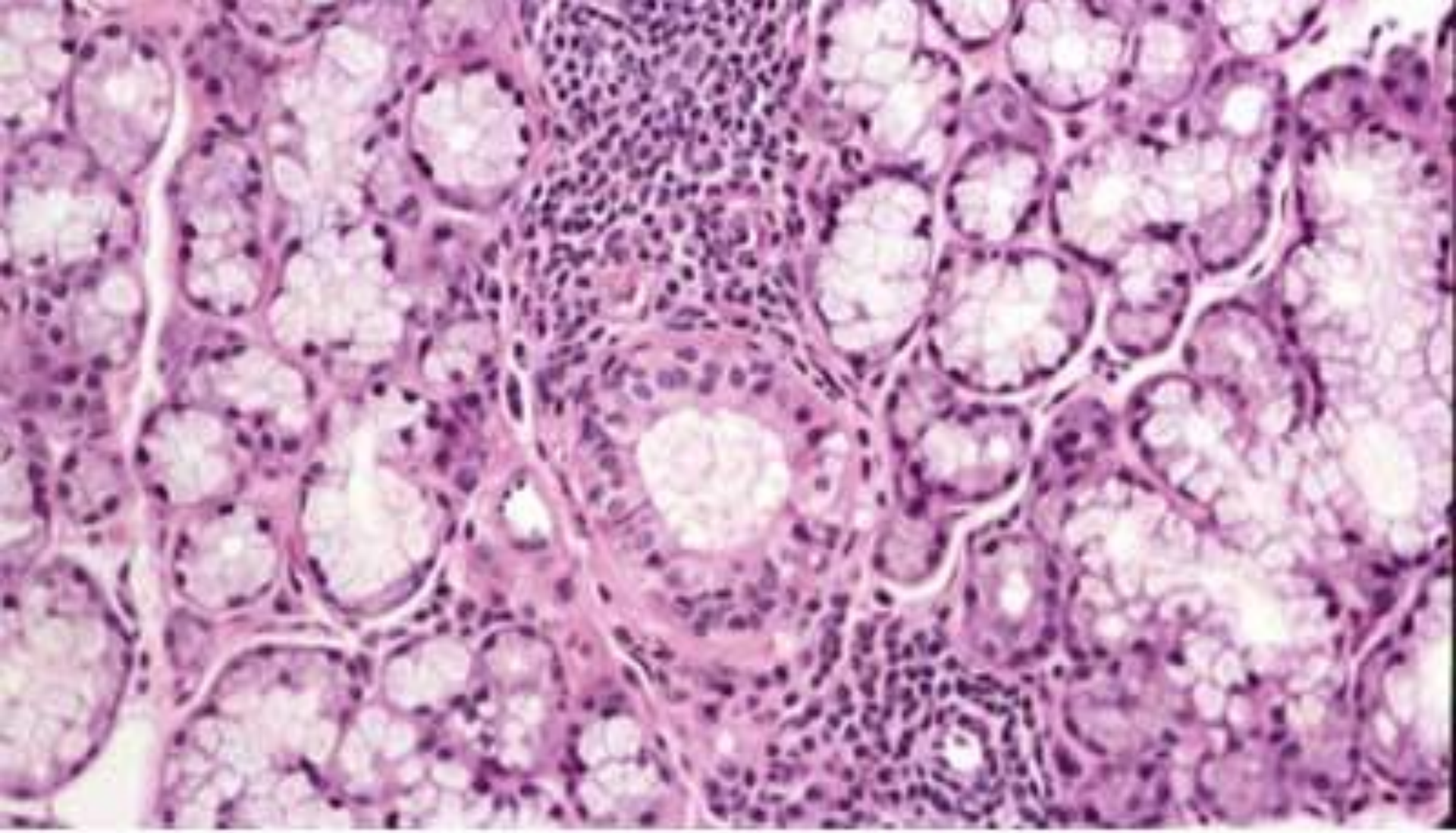

GET OCT


GET OCT

Meibomian Gland Dysfunction

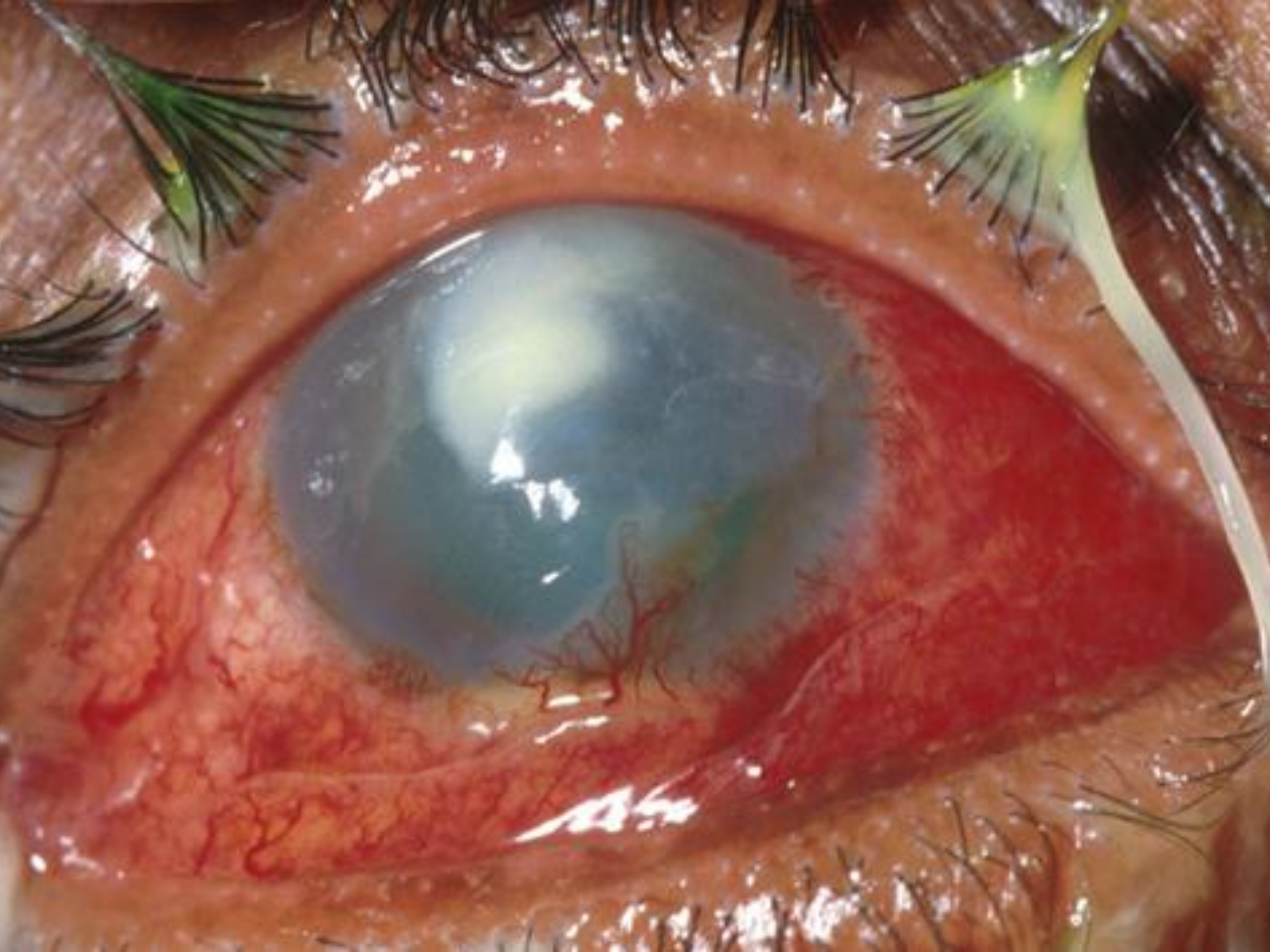


Blepharitis



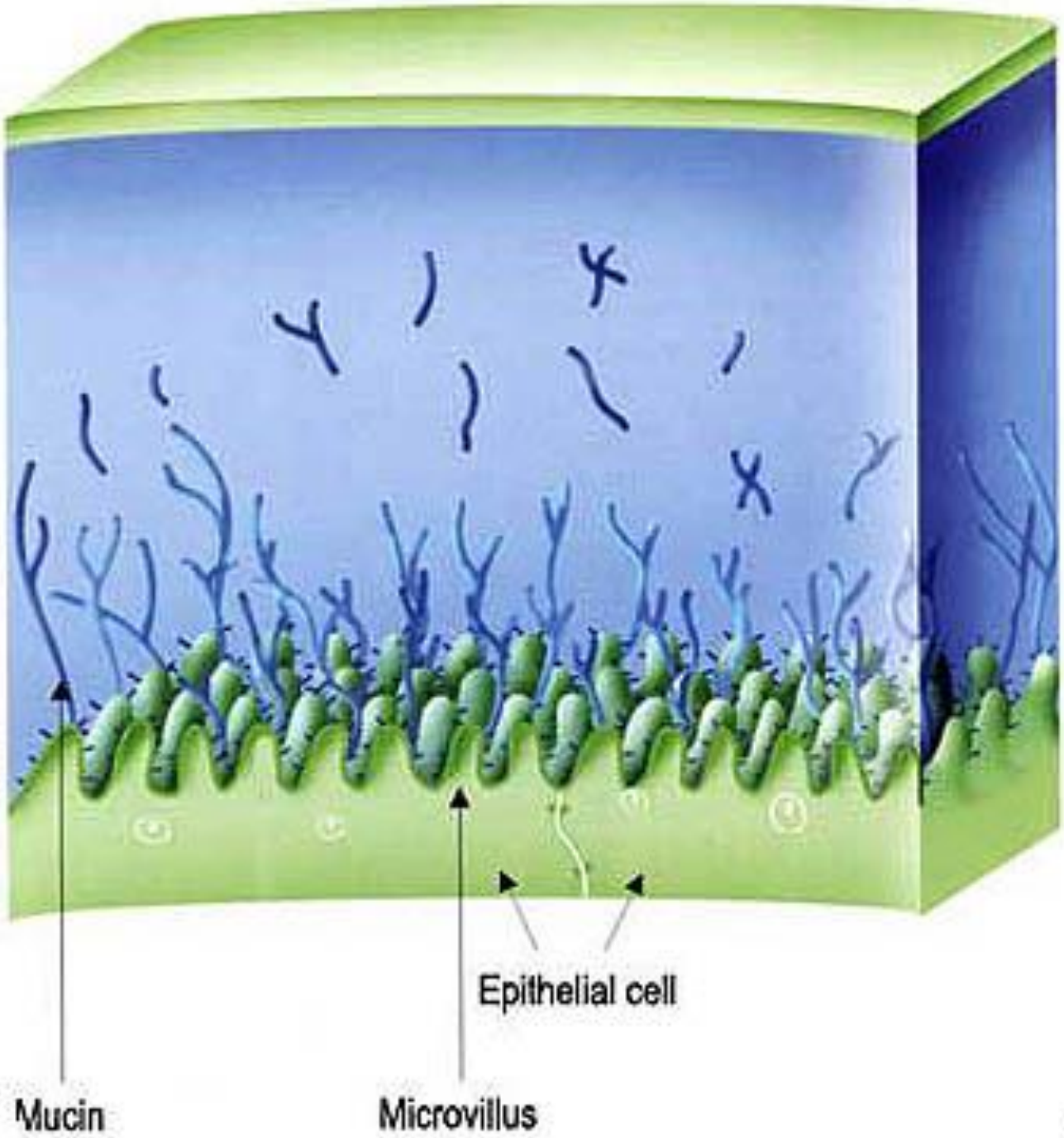
The slide shows a classic focal lymphocytic infiltration in a minor salivary gland section stained with hematoxylin and eosin. These findings are typical of Sjogren's syndrome.

Courtesy of NIH/NIDCR.



3 Layers of Tear Film

- Lipid Layer – top 0.1µm – Prevents Evaporation – Disrupted in Blepharitis, Rosacea
- Water Layer – mid 8µm – Hydration, Oxygenation, Bactericidal Effect – Deficient in Old Age, Sjogren's Syndrome
- Mucin Layer – bottom 0.8µm – Surface Wetting – Deficient in Chemical Burn, Steven Johnson's Syndrome



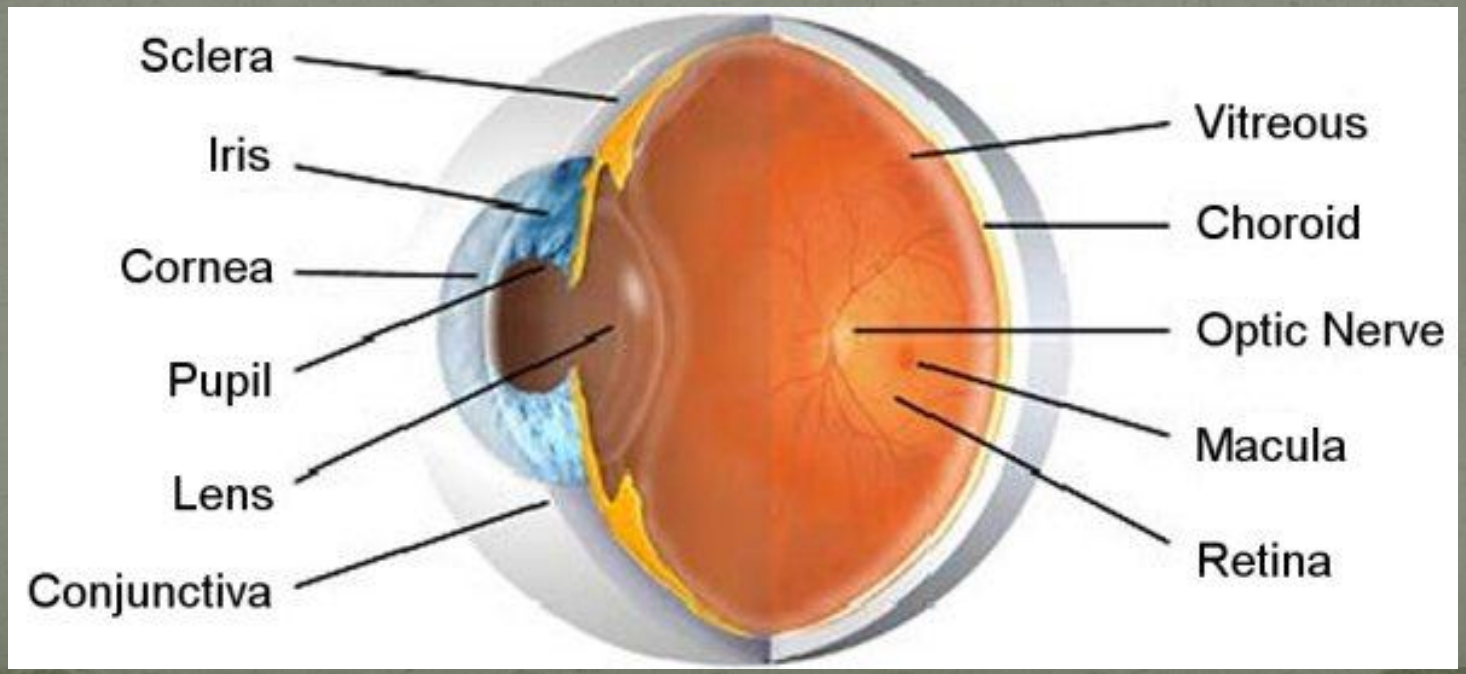
With kind permission from Allergan

Sclera

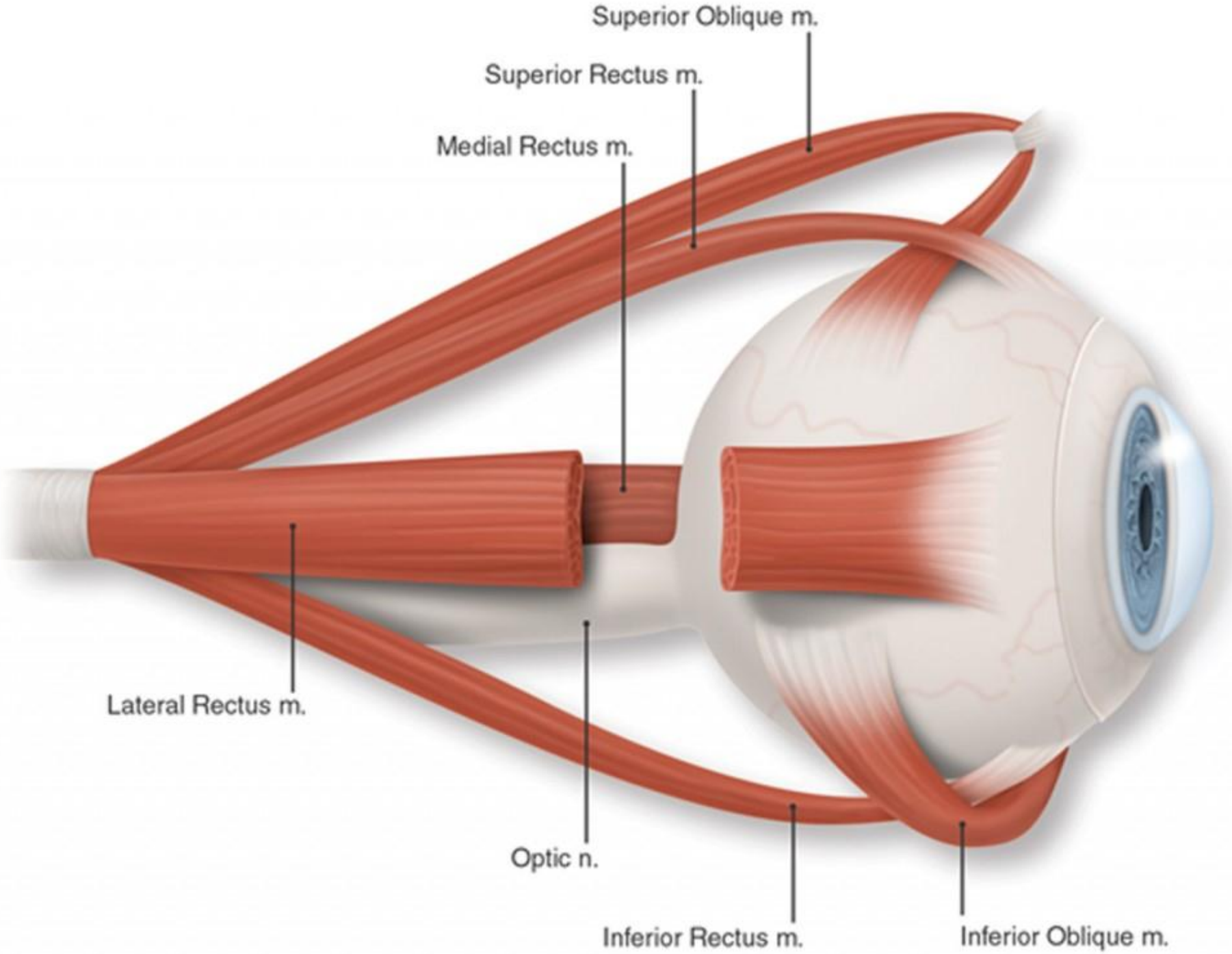
- Structure
  - Opaque
  - Tough
  - Irregularly arranged collagen fibres
- Function
  - Shape maintenance
  - Infection and trauma barriers
  - IOP maintenance (by resistance of IOP)

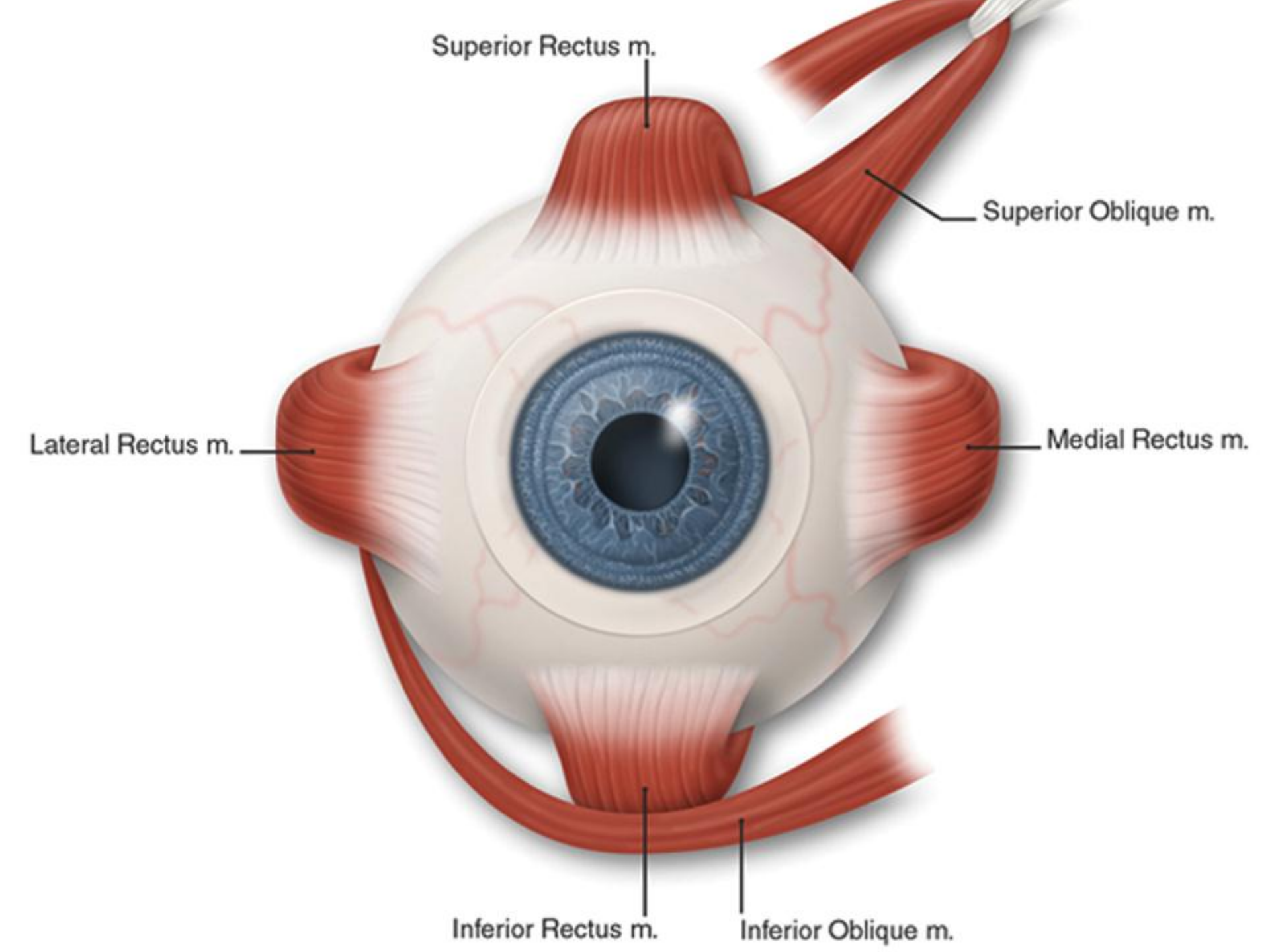
Three Layers of the Coat of the Eye

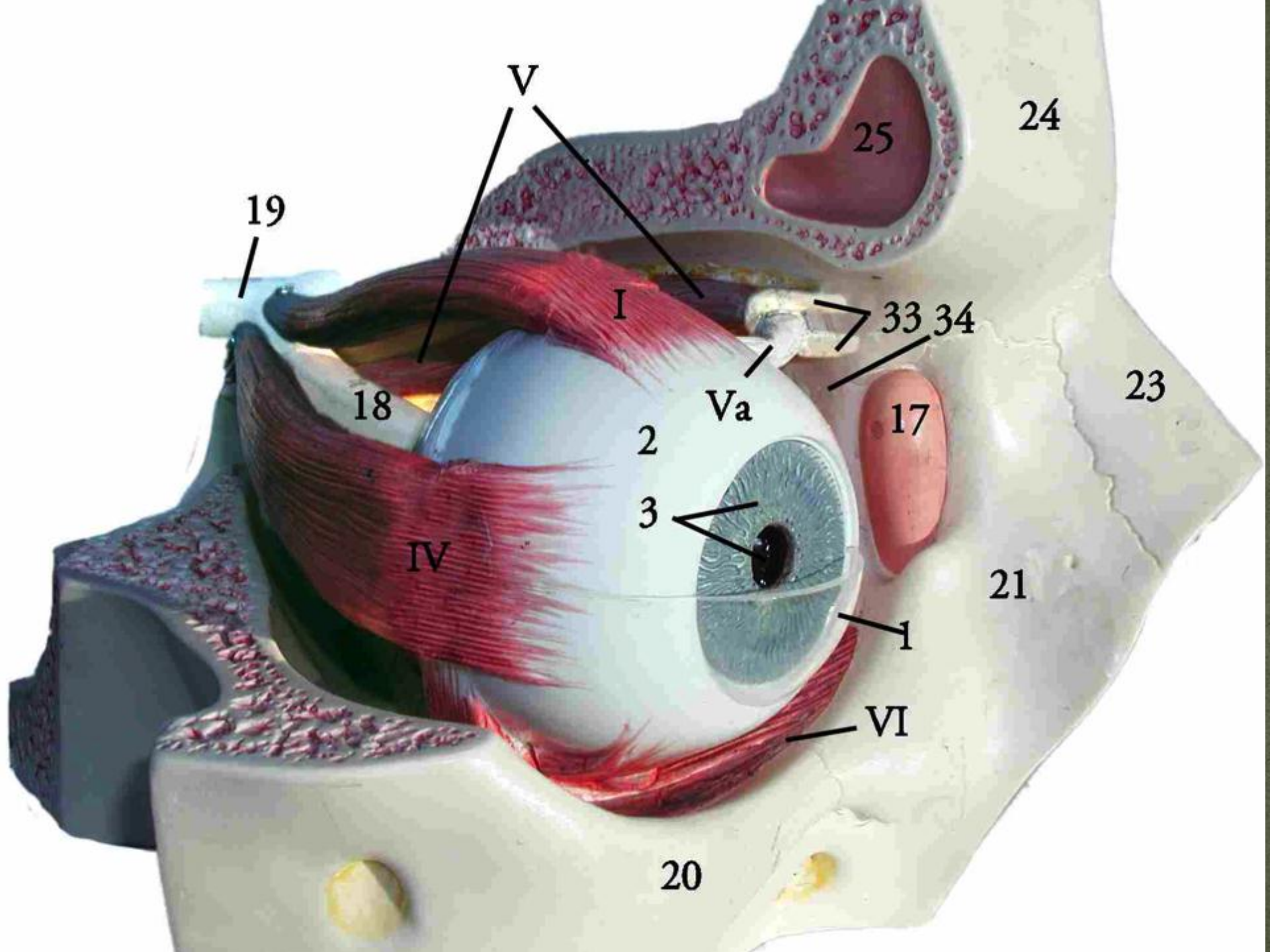
- Sclera – Physical Protection
- Uvea – Circulation, Pigment (absorbs stray light)
- Neuroretina – Detects Light

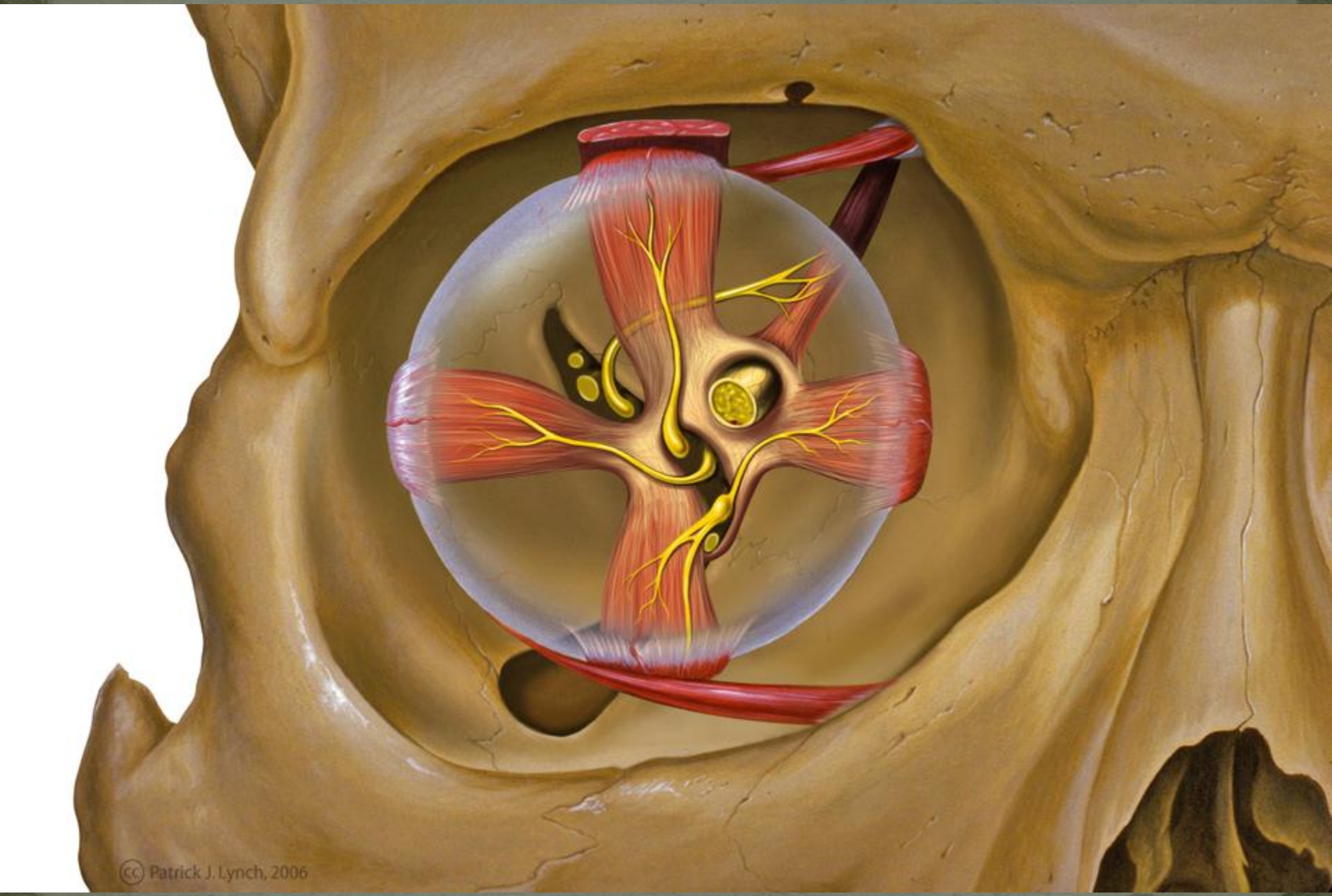


Part II Eye Movement


Superior Oblique m.
Superior Rectus m.
Medial Rectus m.
Lateral Rectus m.
Optic n.
Inferior Rectus m.
Inferior Oblique m.


Superior Rectus m.
Superior Oblique m.
Lateral Rectus m.
Medial Rectus m.
Inferior Rectus m.
Inferior Oblique m.


V
24
25
19
I
33
34
Va
23
18
17
2
3
IV
21
1
VI
20


© Patrick J. Lynch, 2006

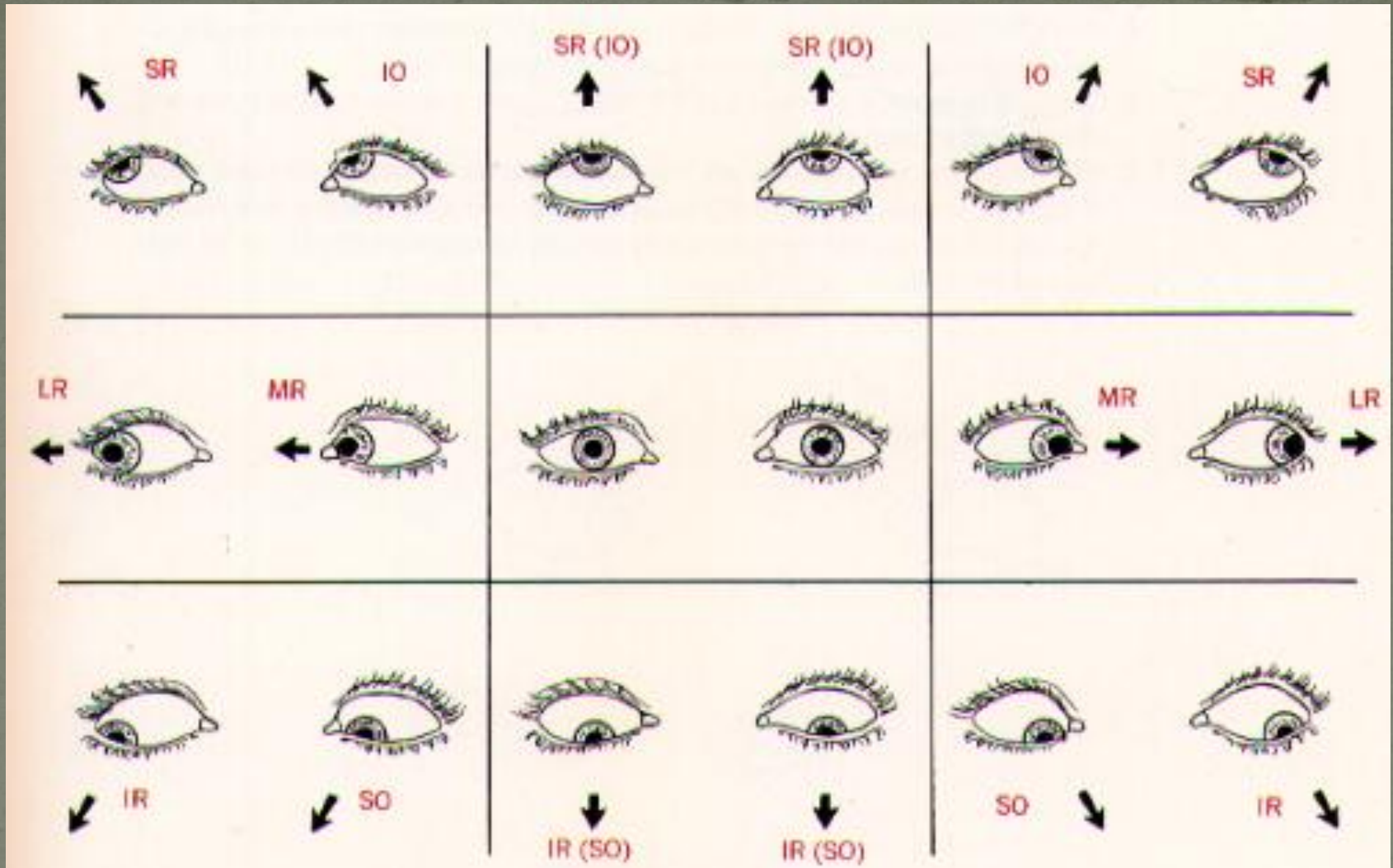


Figure 12

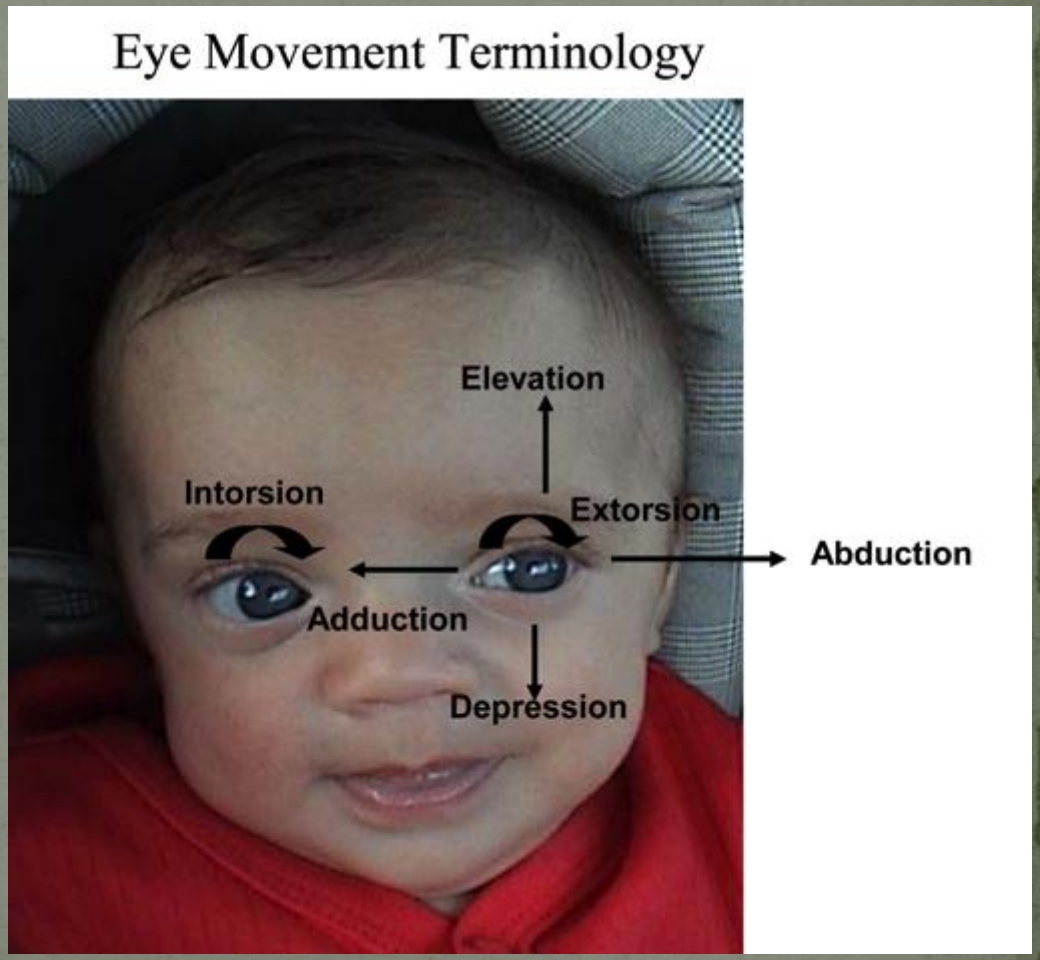
MR=medial rectus; LR=lateral rectus; SR=superior rectus;
IR=inferior rectus; So=superior oblique; IR=inferior oblique

Types of Eye Movement - Coordination

- Duction – Eye Movement in one eye
- Version – Simultaneous Movement in both eyes in the same direction
- Vergence – Simultaneous Movement in both eyes in opposite direction – convergence, divergence

Types of Eye Movement - Direction

- Elevation, Supraduction, Supraversion – Up
- Depression, Infraduction, Infraversion – Down
- Dextroversion – Right
- Levoversion – Left
- Abduction
- Adduction



Types of Eye Movement - Direction

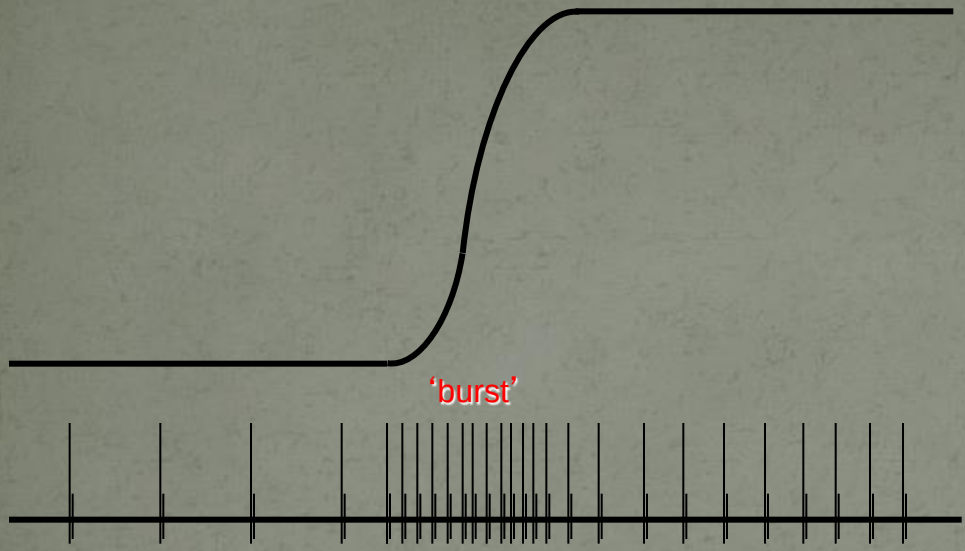
- Extorsion – superior pole of eye tilt outwards
- Intorsion – superior pole of eye tilt inwards
- Dextrotorsion (version) – superior pole of eyes tilt to right
- Levotorsion (version) – superior pole of eyes tilt to left

Types of Eye Movement - Speed

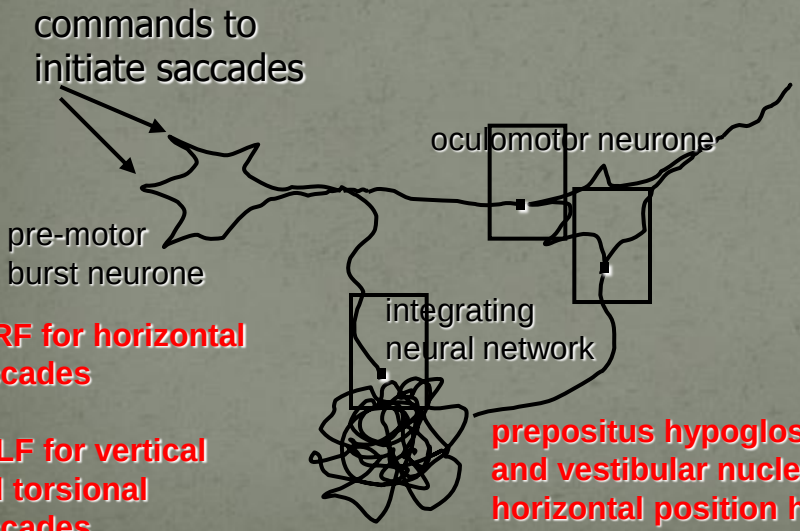
- Saccade – short fast burst, up to 900deg/sec
  - Reflexive saccade to external stimuli
  - Scanning saccade
  - Predictive saccade to track objects
  - Memory-guided saccade
- Smooth Pursuit – sustain slow movement
  - Weak performance up to 60° /s at 0.5 to 1Hz max frequency.
  - Driven by motion of a moving target across the retina.
  - Disorders are sensitive indicators of CNS dysfunction

Saccadic eye movement

Slow phase eye movement



spiking on the oculomotor nerve

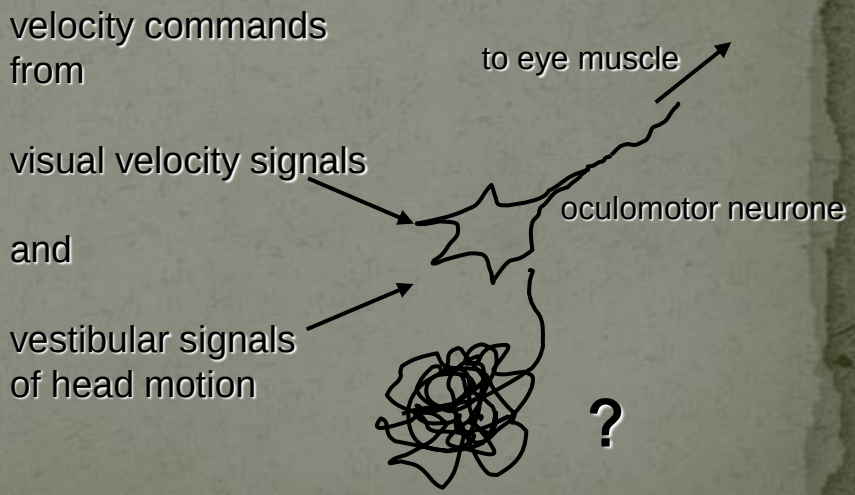


PPRF for horizontal saccades

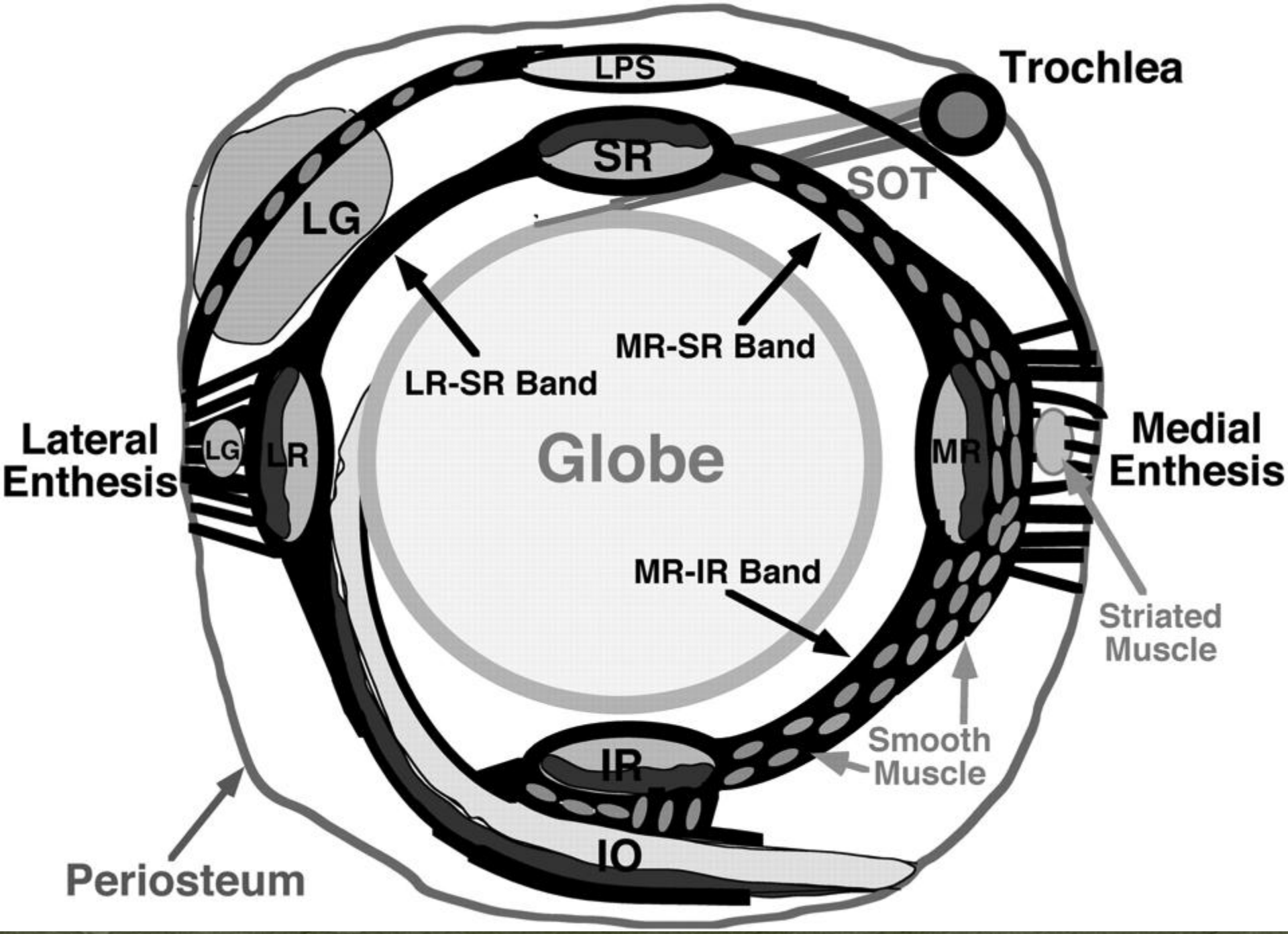
rIMLF for vertical and torsional saccades

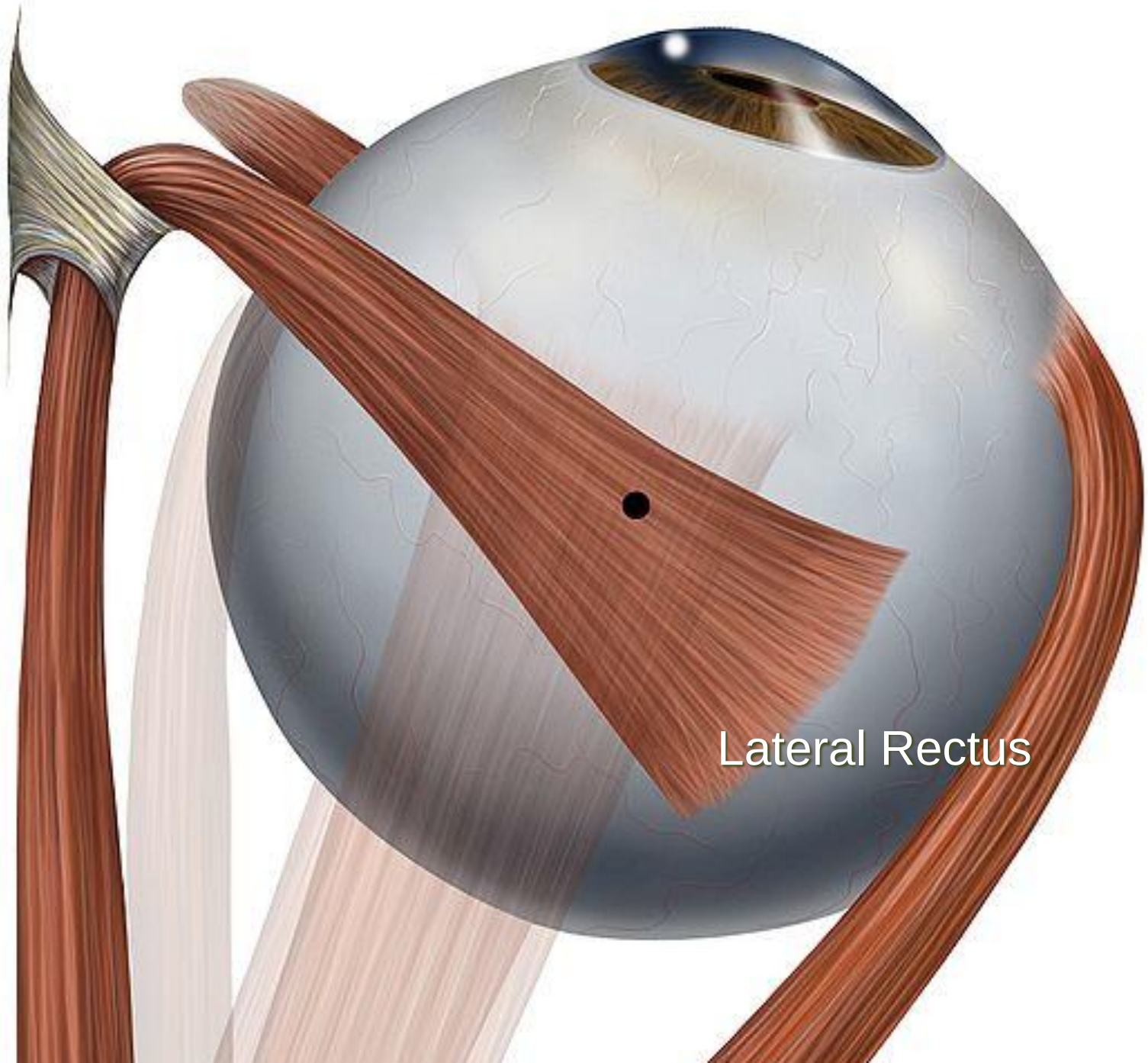
prepositus hypoglossi and vestibular nuclei for horizontal position holding

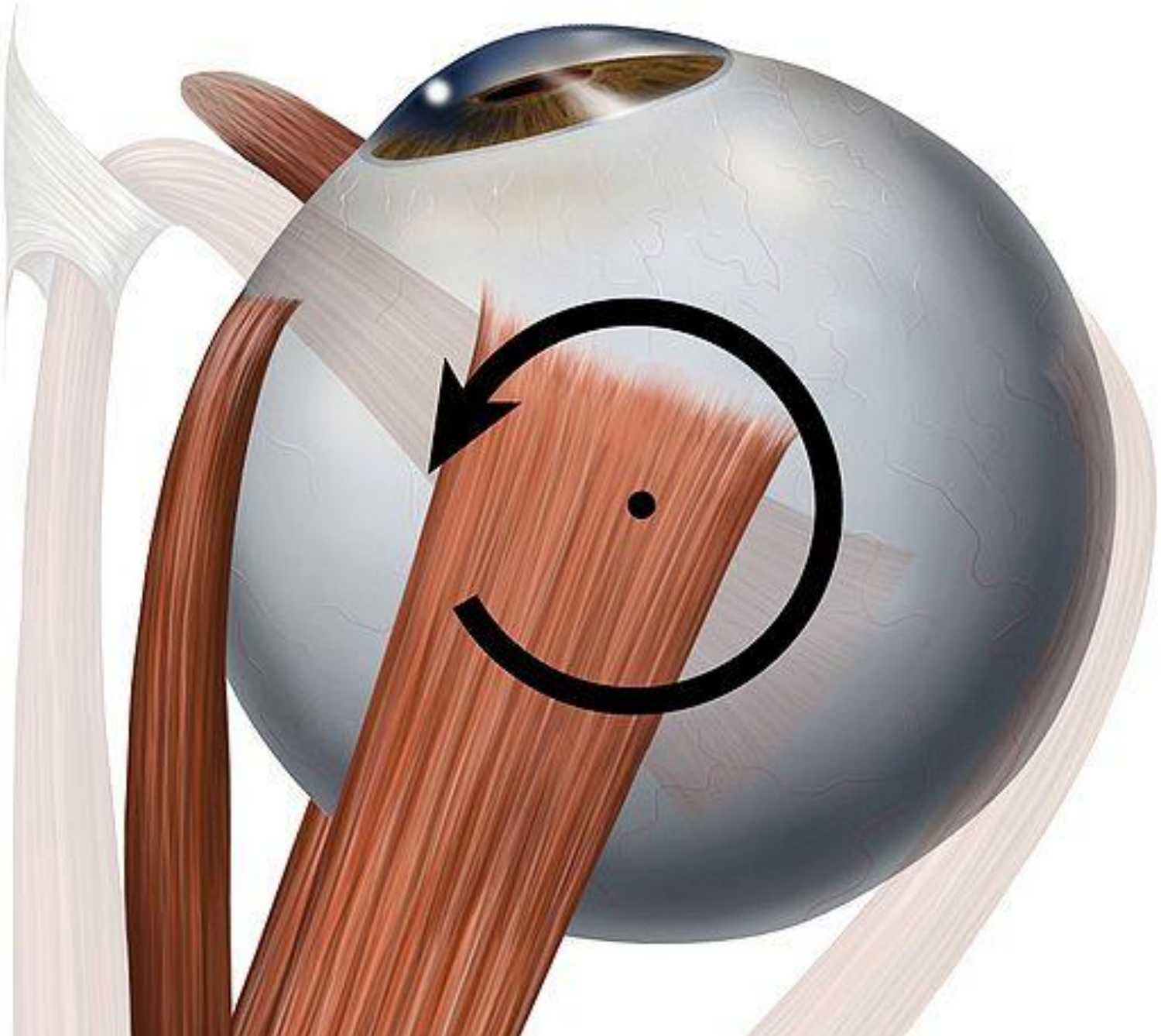
nucleus of Cajal for vertical position holding

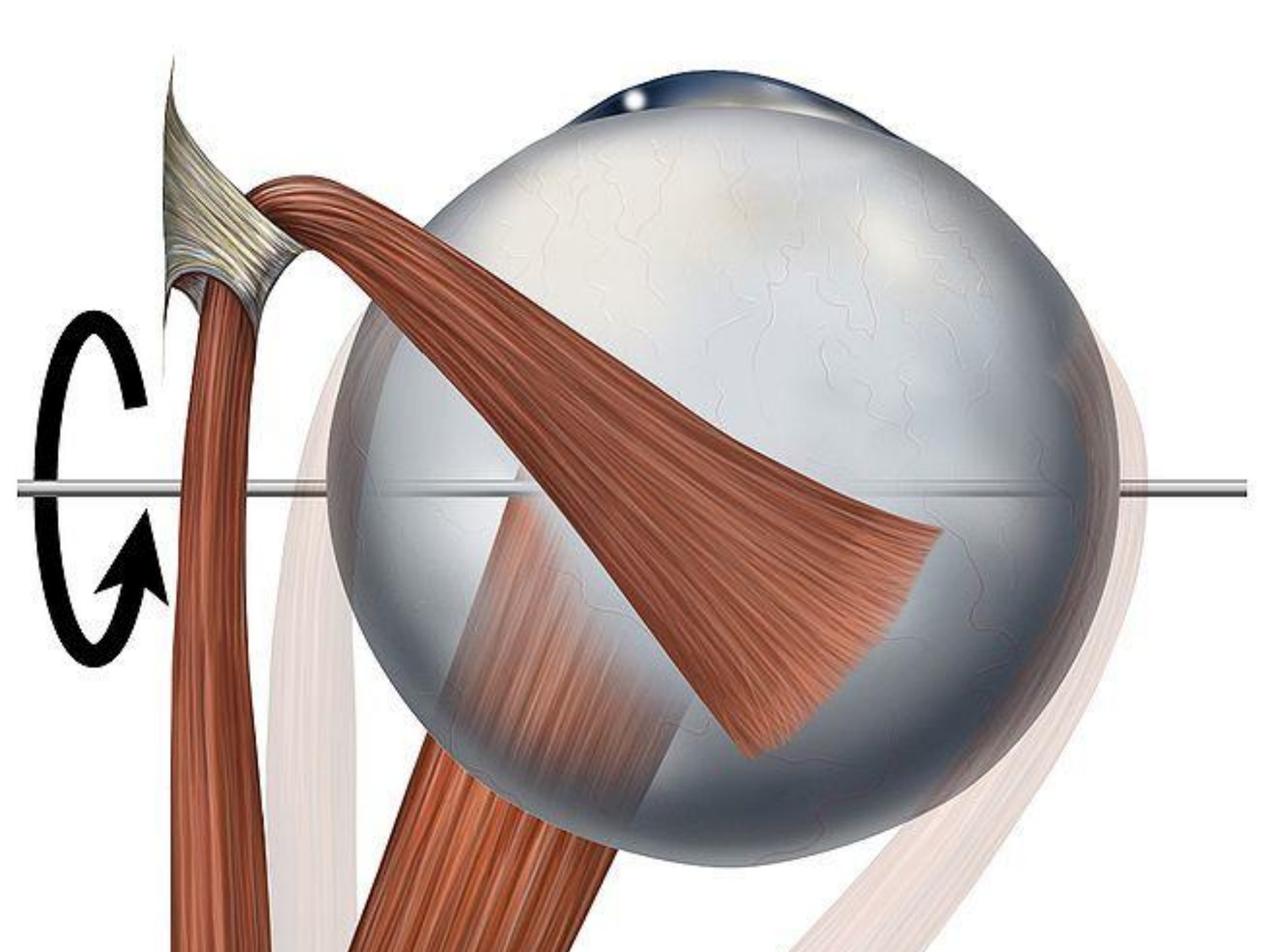


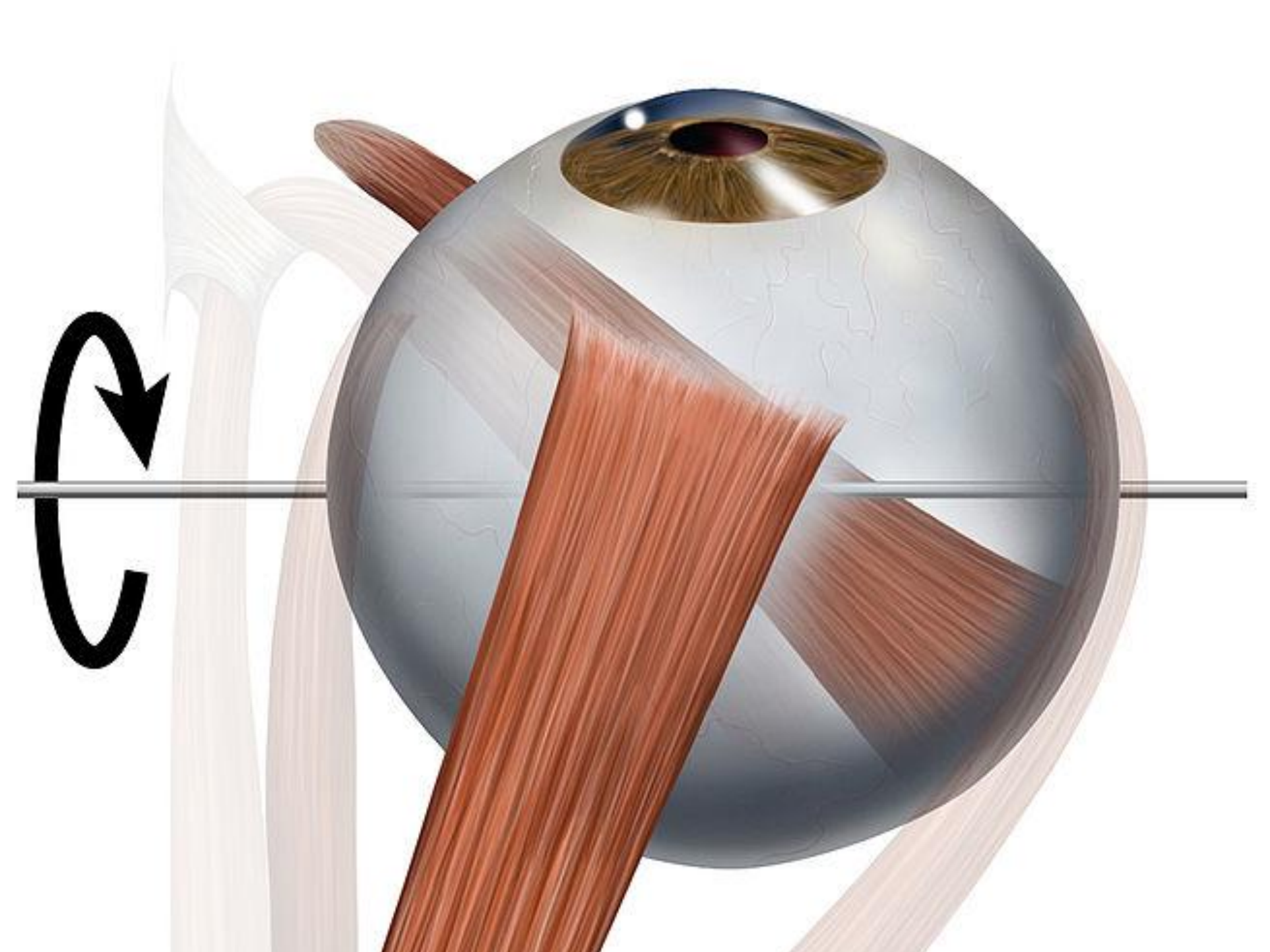
integrating neural network to maintain eye velocity and final position holding

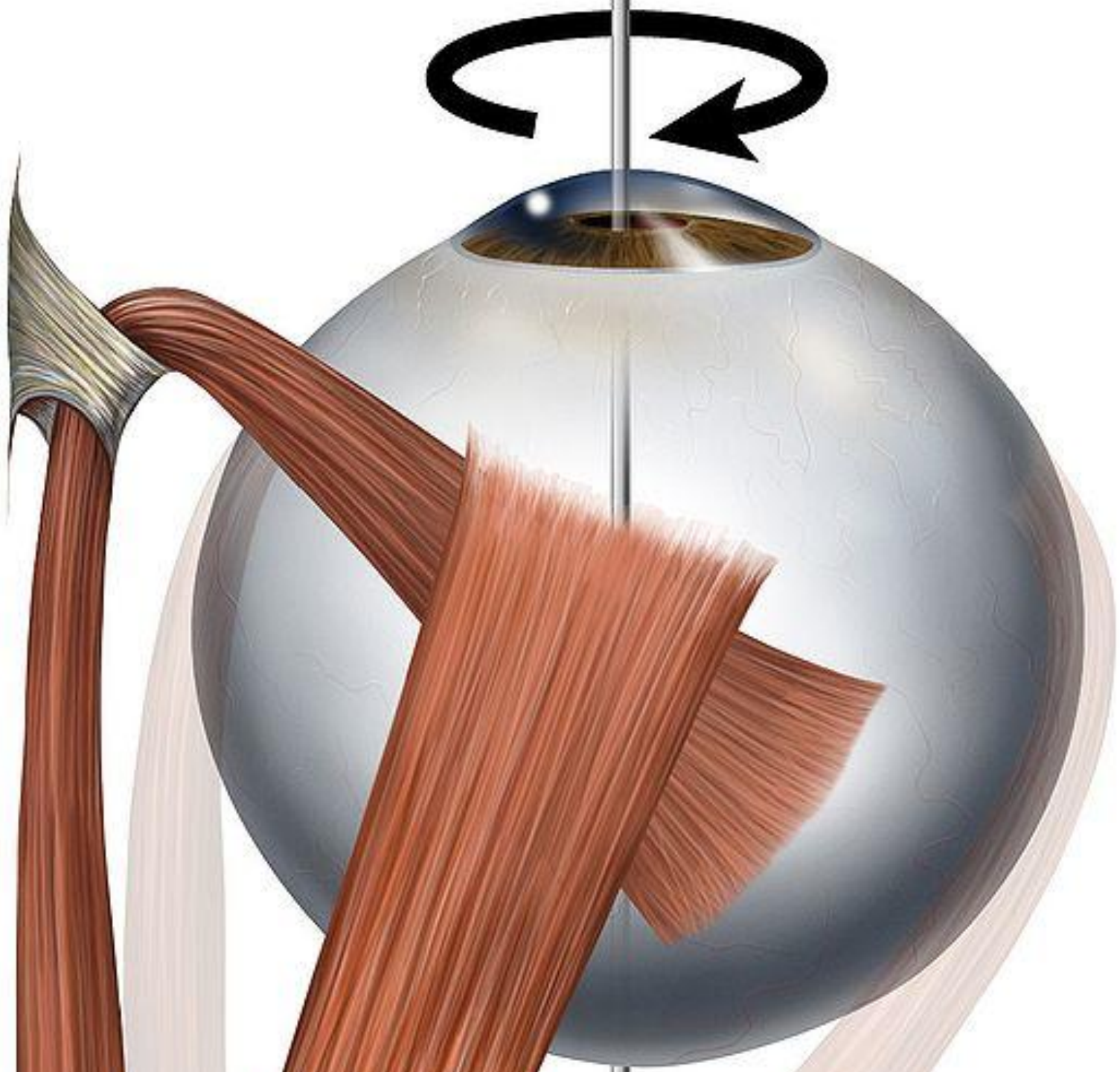

LPS
Trochlea
SR
SOT
LG
MR-SR Band
LR-SR Band
Lateral Enthesis
LG
LR
Globe
MR
Medial Enthesis
MR-IR Band
Striated Muscle
Smooth Muscle
IR
IO
Periosteum

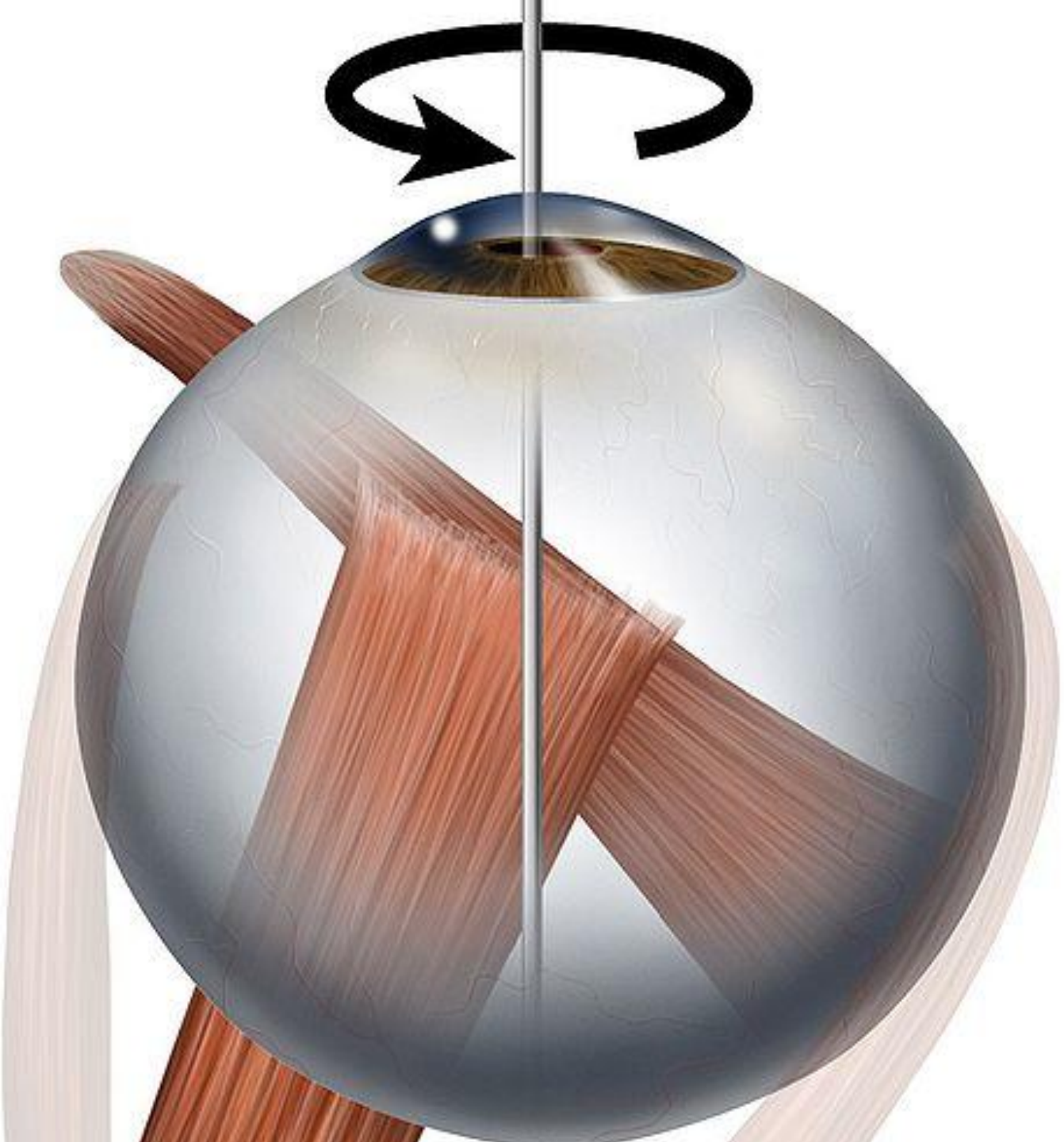

Lateral Rectus

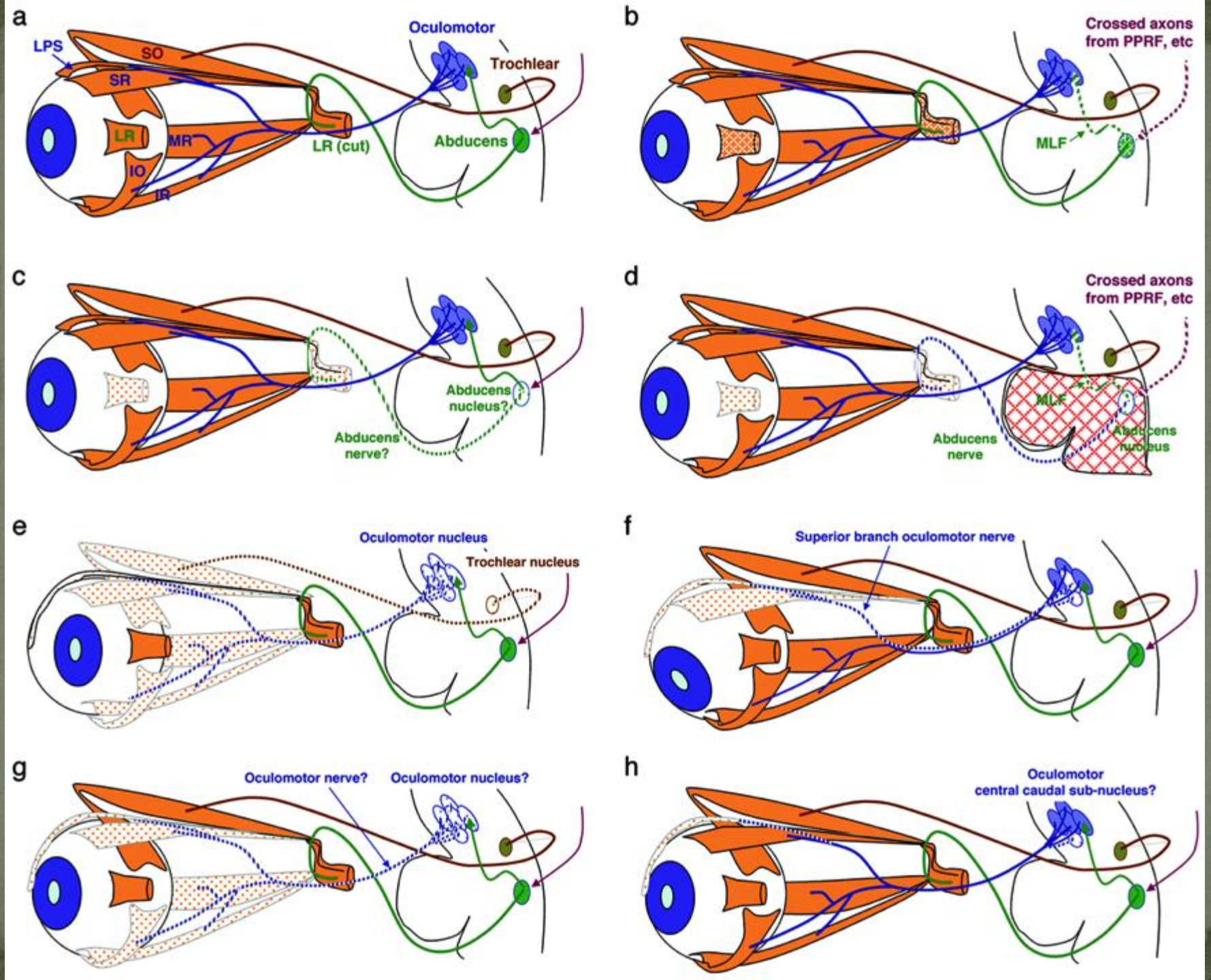






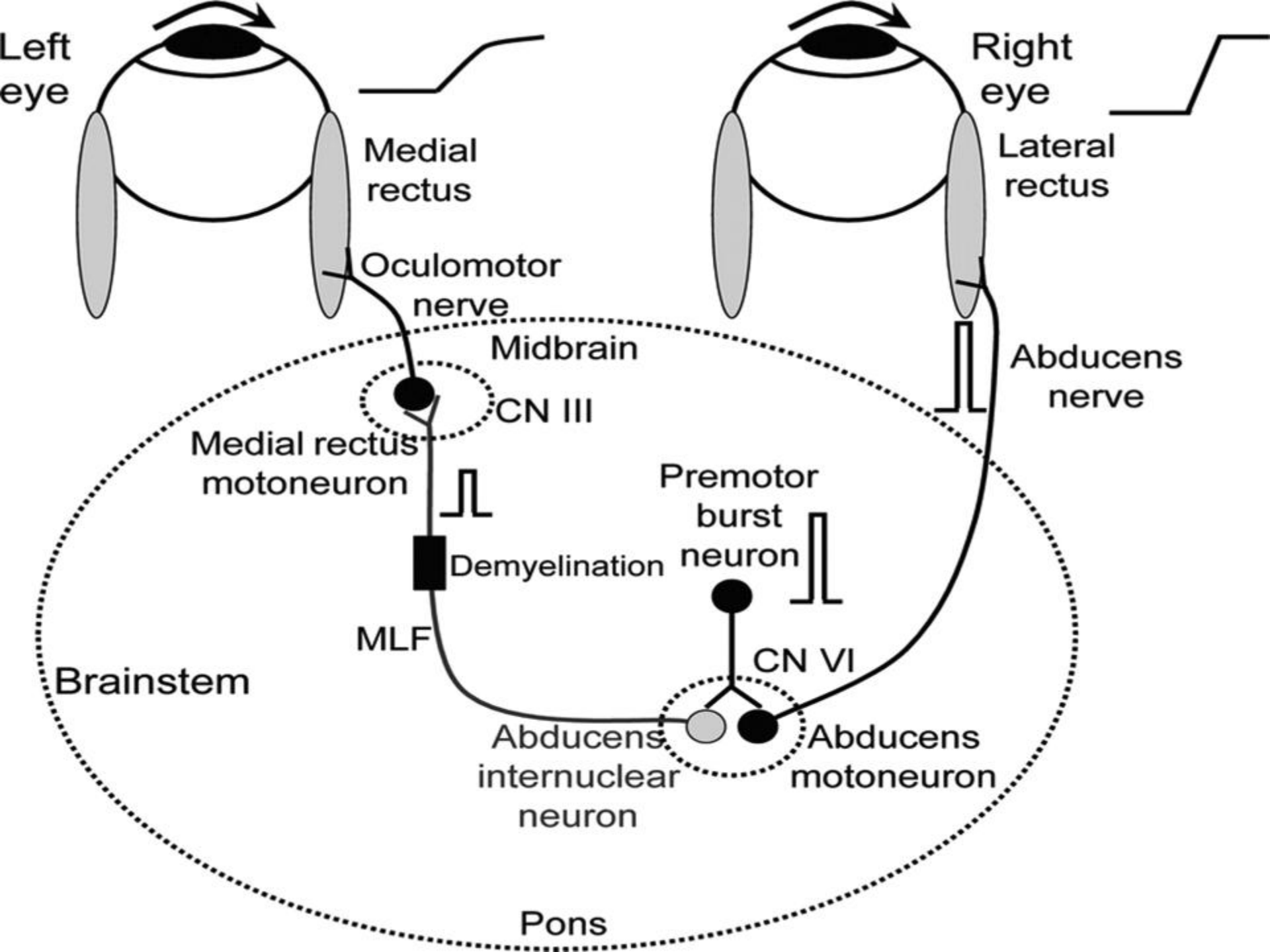


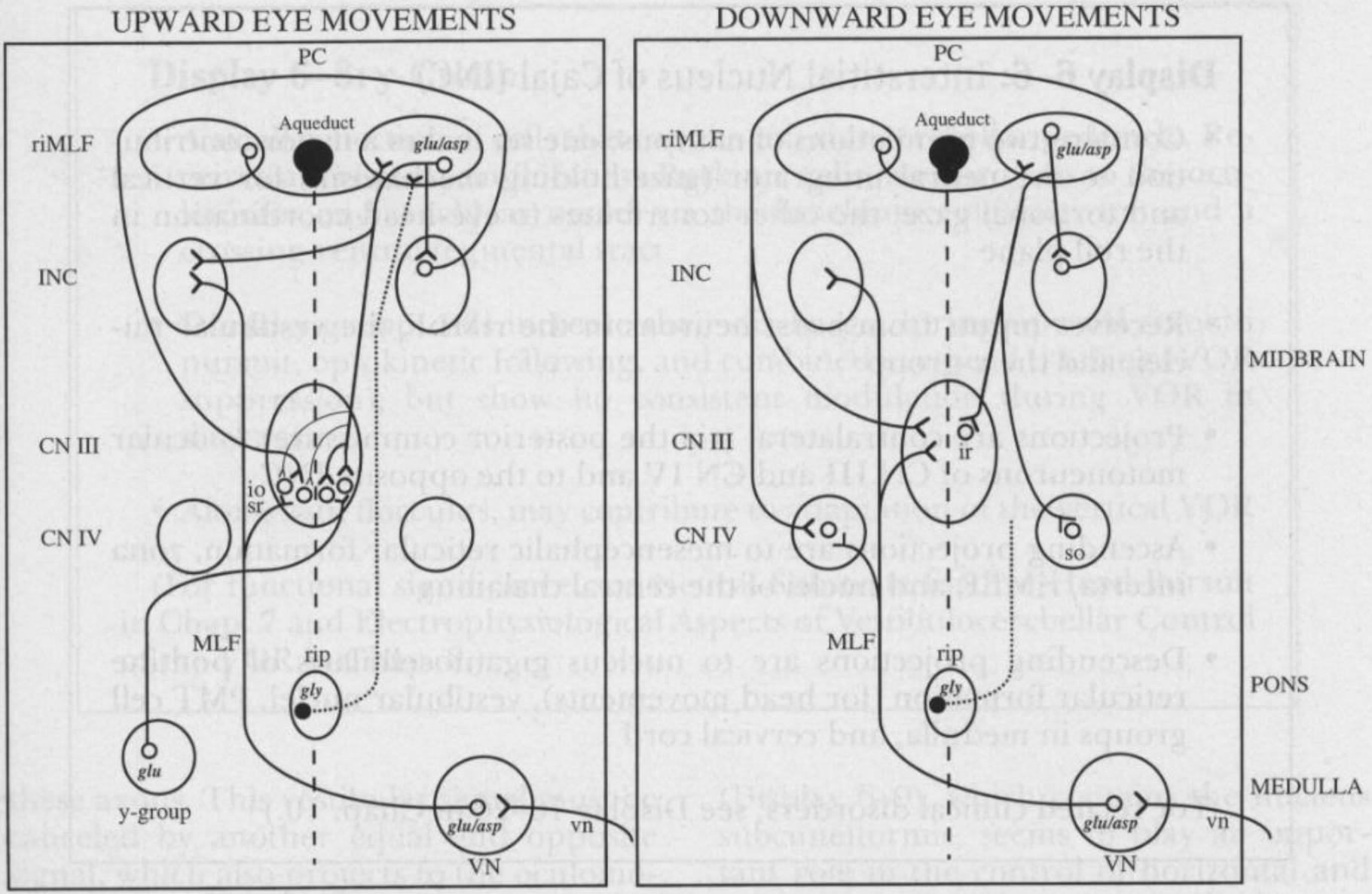



a
LPS
SO
SR
LR
MR
IO
IR
LR (cut)
Oculomotor
Trochlear
Abducens
b
Crossed axons
from PPRF, etc
MLF
c
Abducens
nucleus?
Abducens
nerve?
d
Crossed axons
from PPRF, etc
MLF
Abducens
nerve
Abducens
nucleus
e
Oculomotor nucleus
Trochlear nucleus
f
Superior branch oculomotor nerve
g
Oculomotor nerve?
Oculomotor nucleus?
h
Oculomotor
central caudal sub-nucleus?

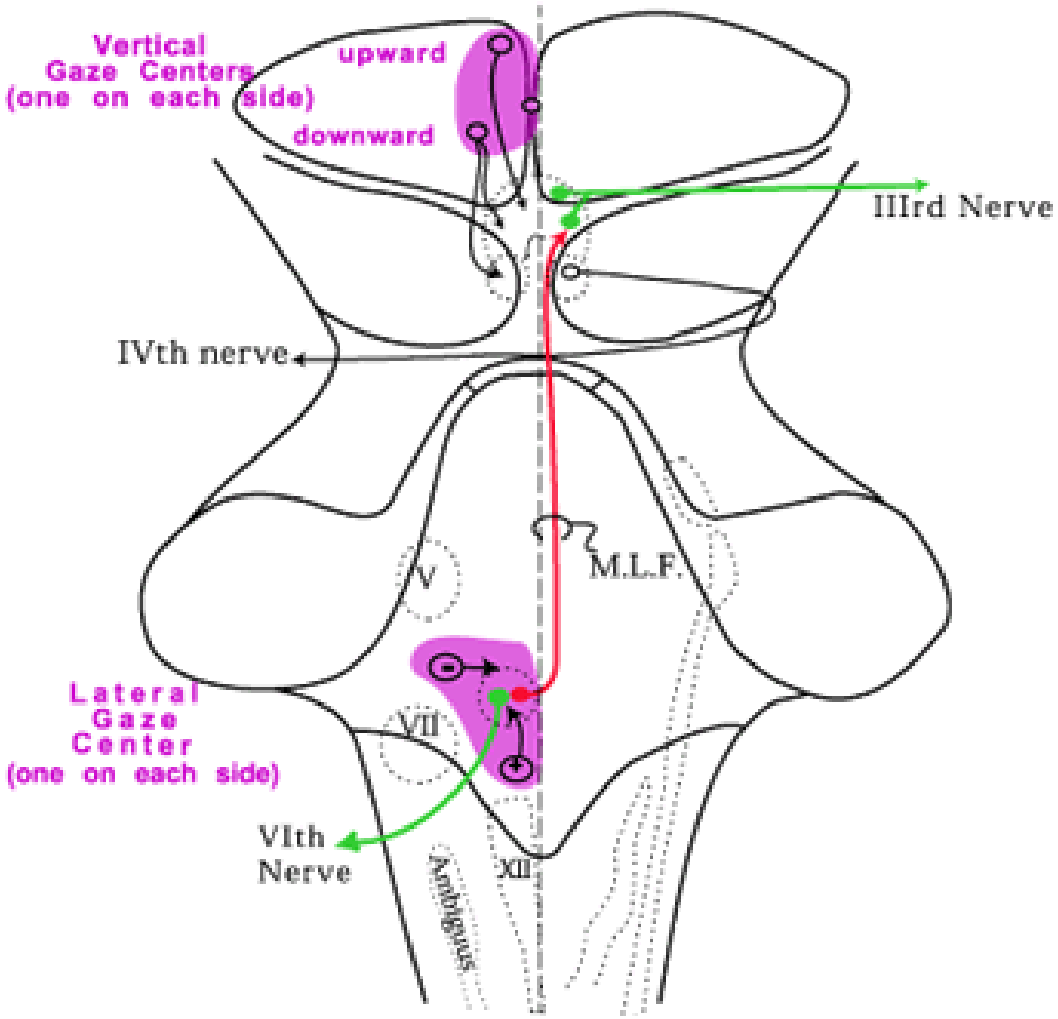
Horizontal Version Movement

- Hering's Law of Innervation – conjugate movements are due to innate innervation
- For example dextroversion – equal innervation to right eye lateral rectus (abduction, 6th nerve) and left eye medial rectus (adduction 3rd nerve)
- Sherrington's Law of Reciprocal Innervation – antagonist muscles relaxes
- For example dextroversion, right eye medial rectus and left eye lateral rectus relax


Left eye
Right eye
Medial rectus
Lateral rectus
Oculomotor nerve
Midbrain
Abducens nerve
CN III
Medial rectus motoneuron
Premotor burst neuron
Demyelination
MLF
CN VI
Brainstem
Abducens internuclear neuron
Abducens motoneuron
Pons

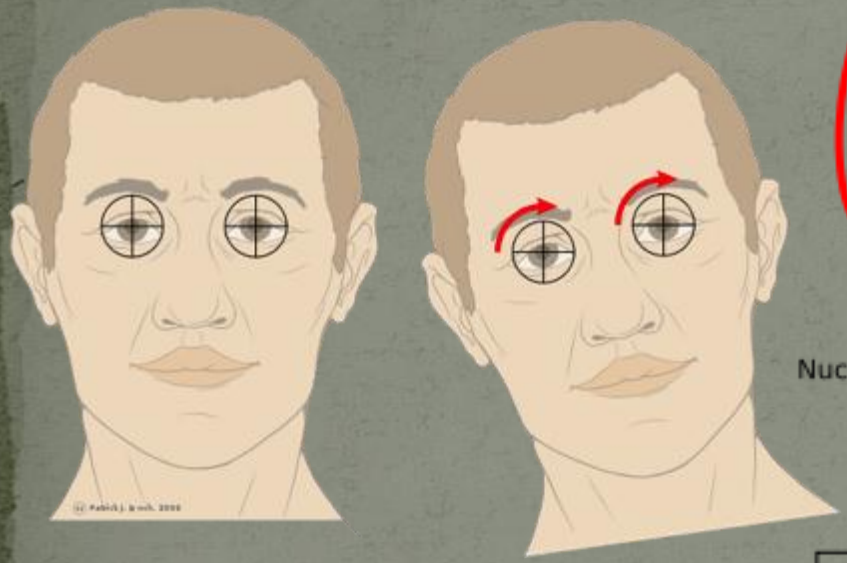

UPWARD EYE MOVEMENTS
DOWNWARD EYE MOVEMENTS
PC
Aqueduct
riMLF
glu/asp
INC
CN III
CN IV
io
sr
MLF
rip
gly
glu
y-group
glu/asp
VN
vn
ir
so
MIDBRAIN
PONS
MEDULLA

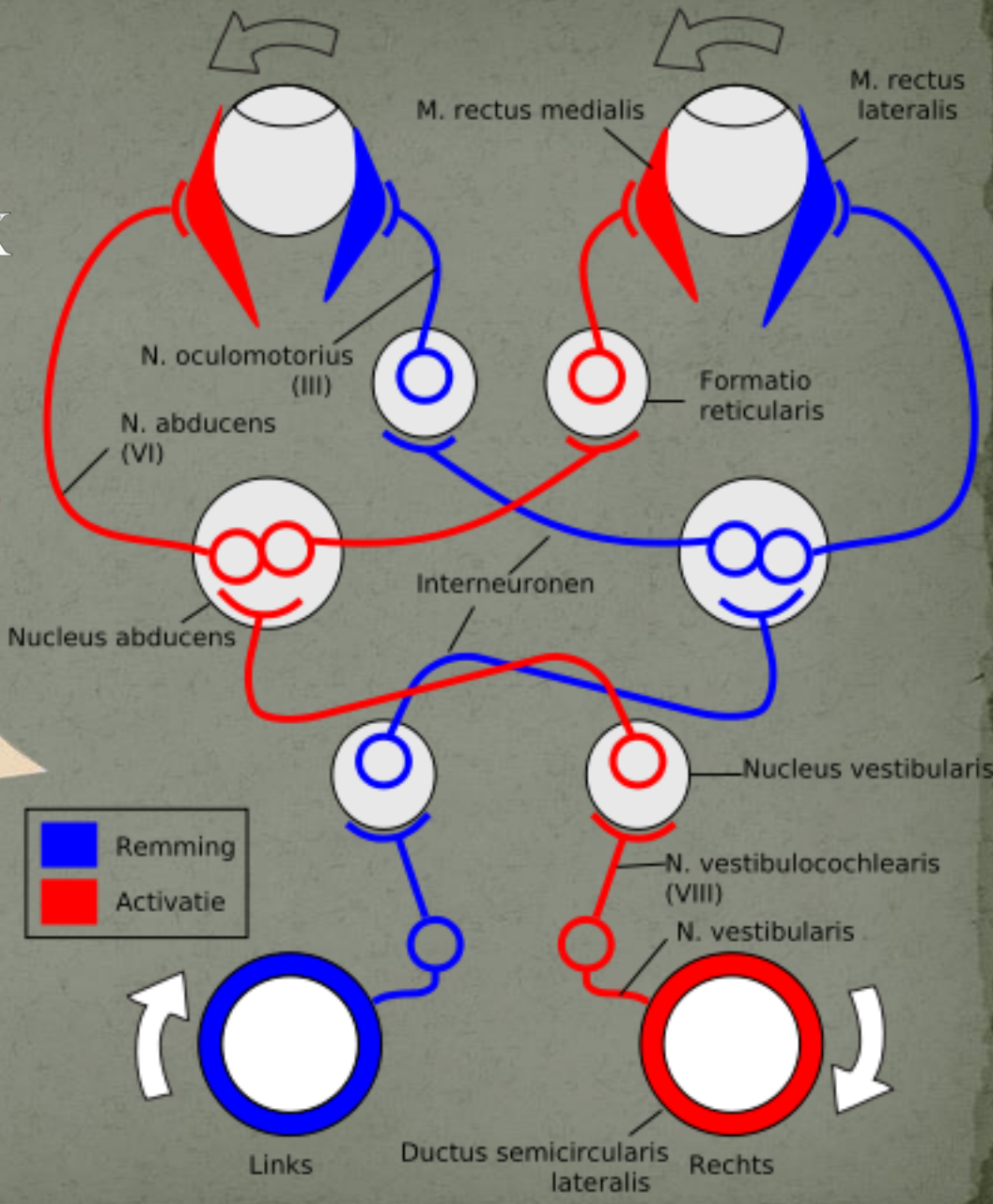
Brainstem wiring for Voluntary Eye Movements



Schematic diagram of the brainstem centers for lateral and vertical gaze, shown on the outline already used for brainstem and cranial nerve nuclei. For clarity's sake, each gaze center and each extraocular muscle nerve is shown on one side only.

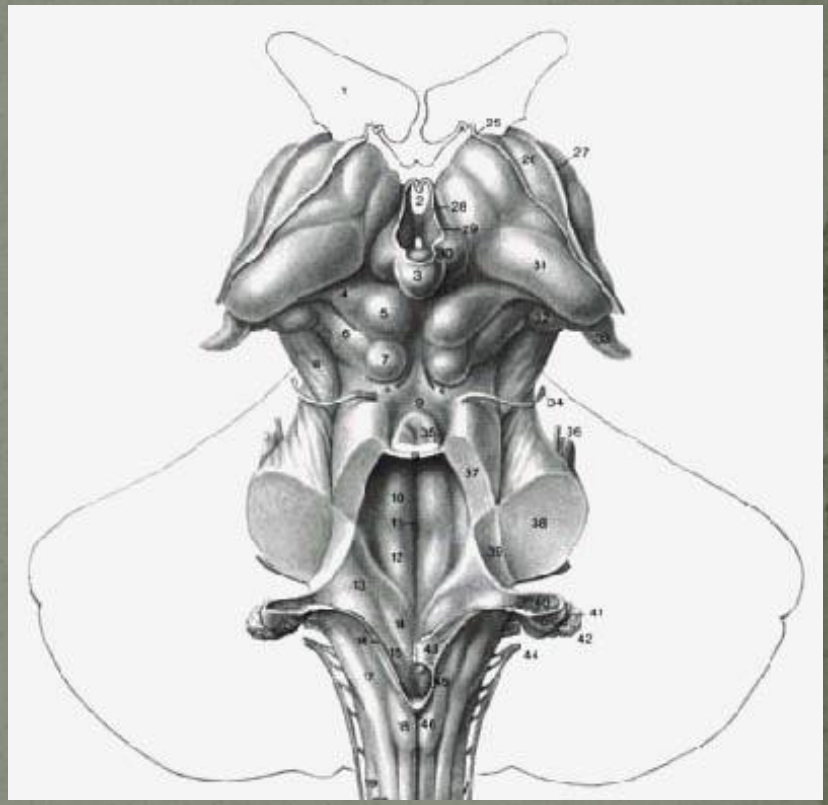
Vestibulo-Ocular Reflex – Gaze Stabilizing Reflex





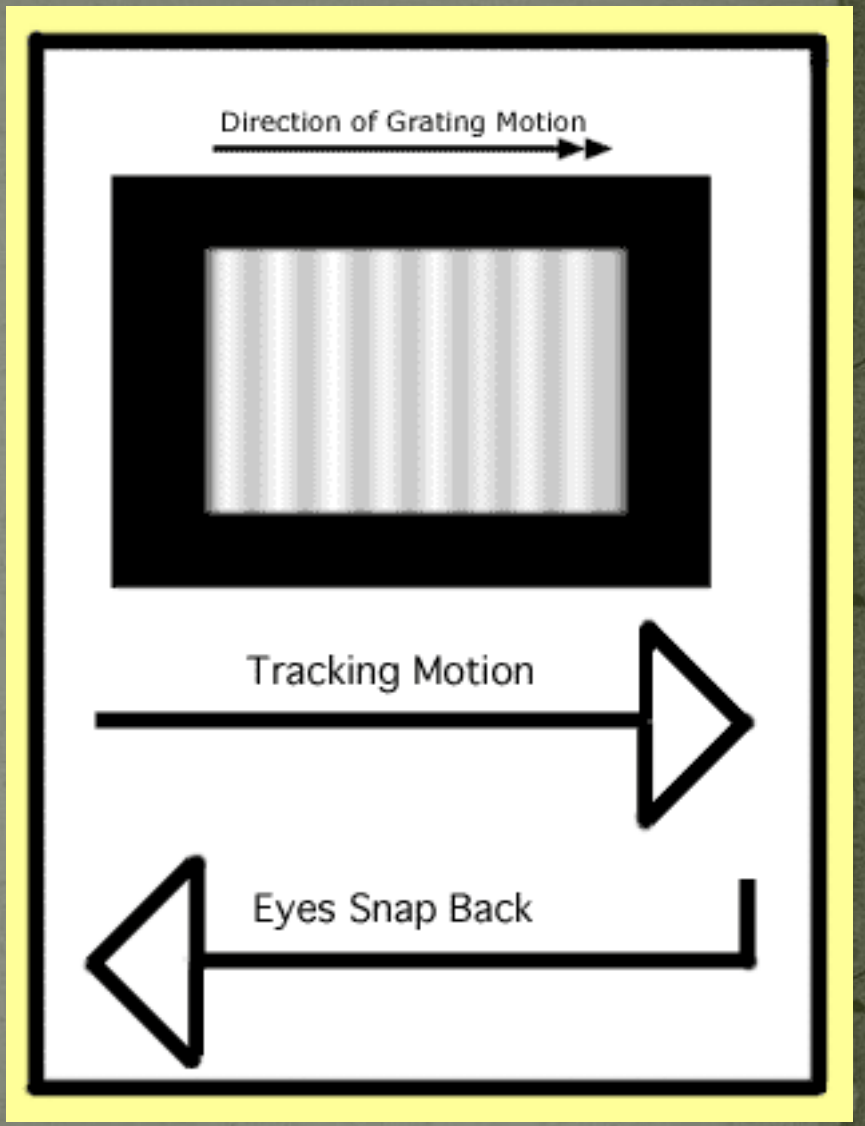
Retino-tectal Pathway

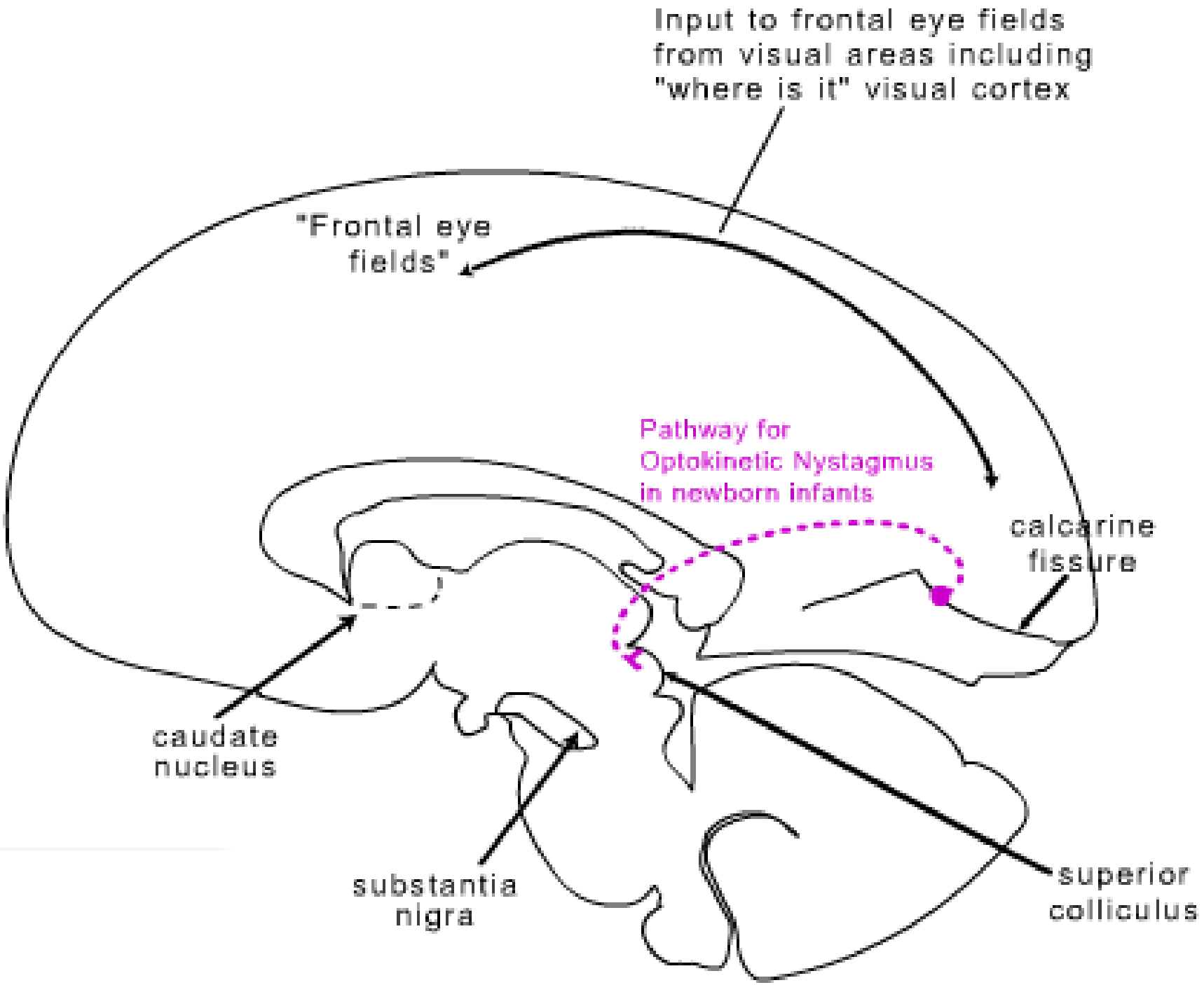
- Projection to superior colliculi
- Generation of saccadic eye movements
- Eye - head coordination
- Also receives inputs from auditory system



Optokinetic Reflex

- Slow phase following driven by motion of an area of the visual field.
- The cumulative eye deviation is rest by fast phases: 'optokinetic nystagmus'
- Function of OKN is to complement the vestibular-ocular reflex by signaling sustained motion




Input to frontal eye fields
from visual areas including
"where is it" visual cortex
"Frontal eye
fields"
Pathway for
Optokinetic Nystagmus
in newborn infants
calcarine
fissure
caudate
nucleus
substantia
nigra
superior
colliculus

OKN Drum Assessing Baby Vision

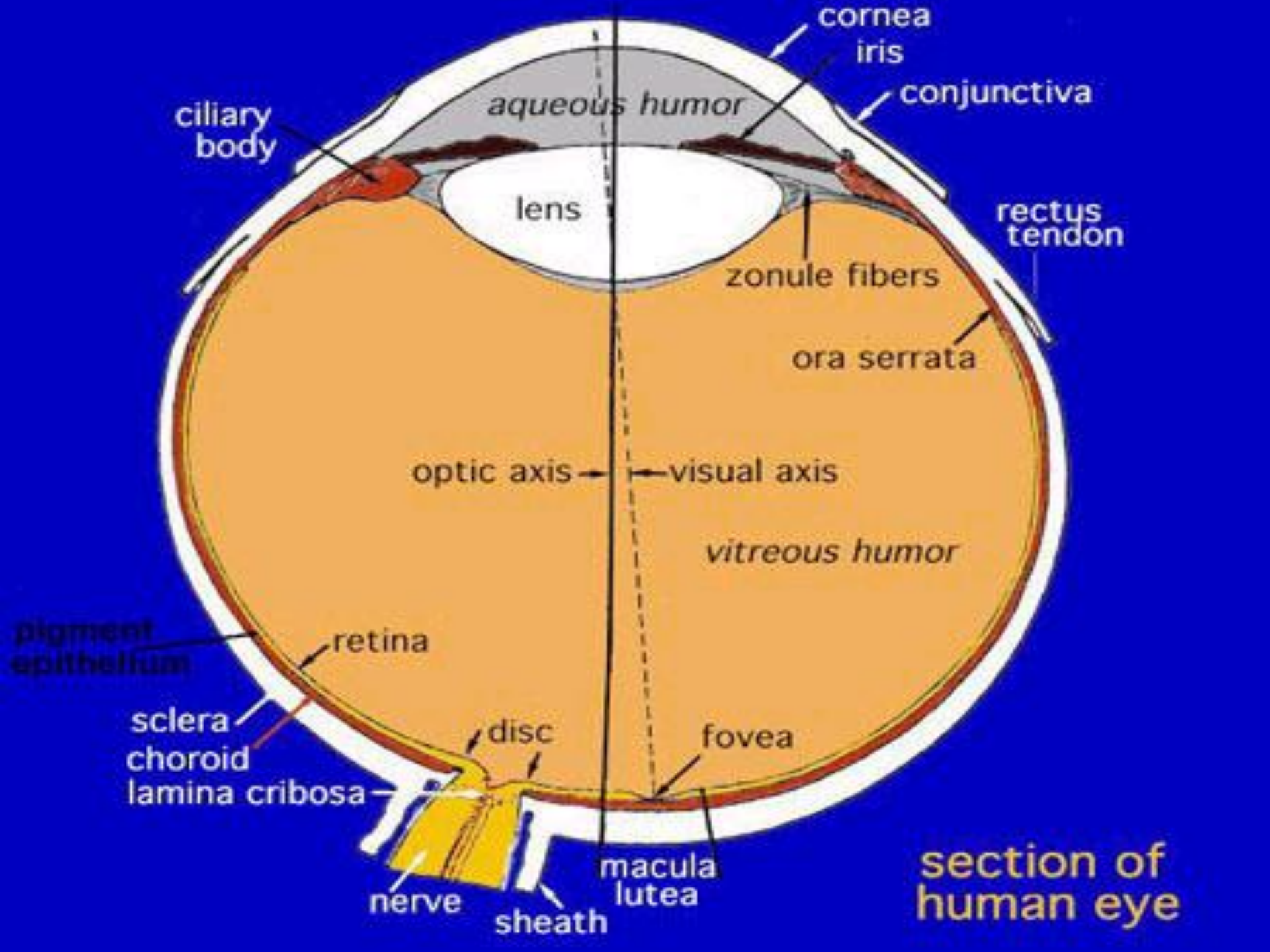
Abnormal Eye Movements - Misalignment

- Concomitant Squint – Constant misalignment in all gaze, eg. Childhood Squint
- Nonconmittant Squint – Misalignment varies with gaze, eg. 6th nerve palsy
- Tropia – Misalignment of one eye with respect to the fixating eye, exo – outwards, eso – inwards, hyper – up, hypo – down
- Phoria – Misalignment only apparent after suppressing binocular vision
- Childhood Chronic Onset – No double vision, adult acute onset – double vision

Factors Causing Abnormal Eye Movements

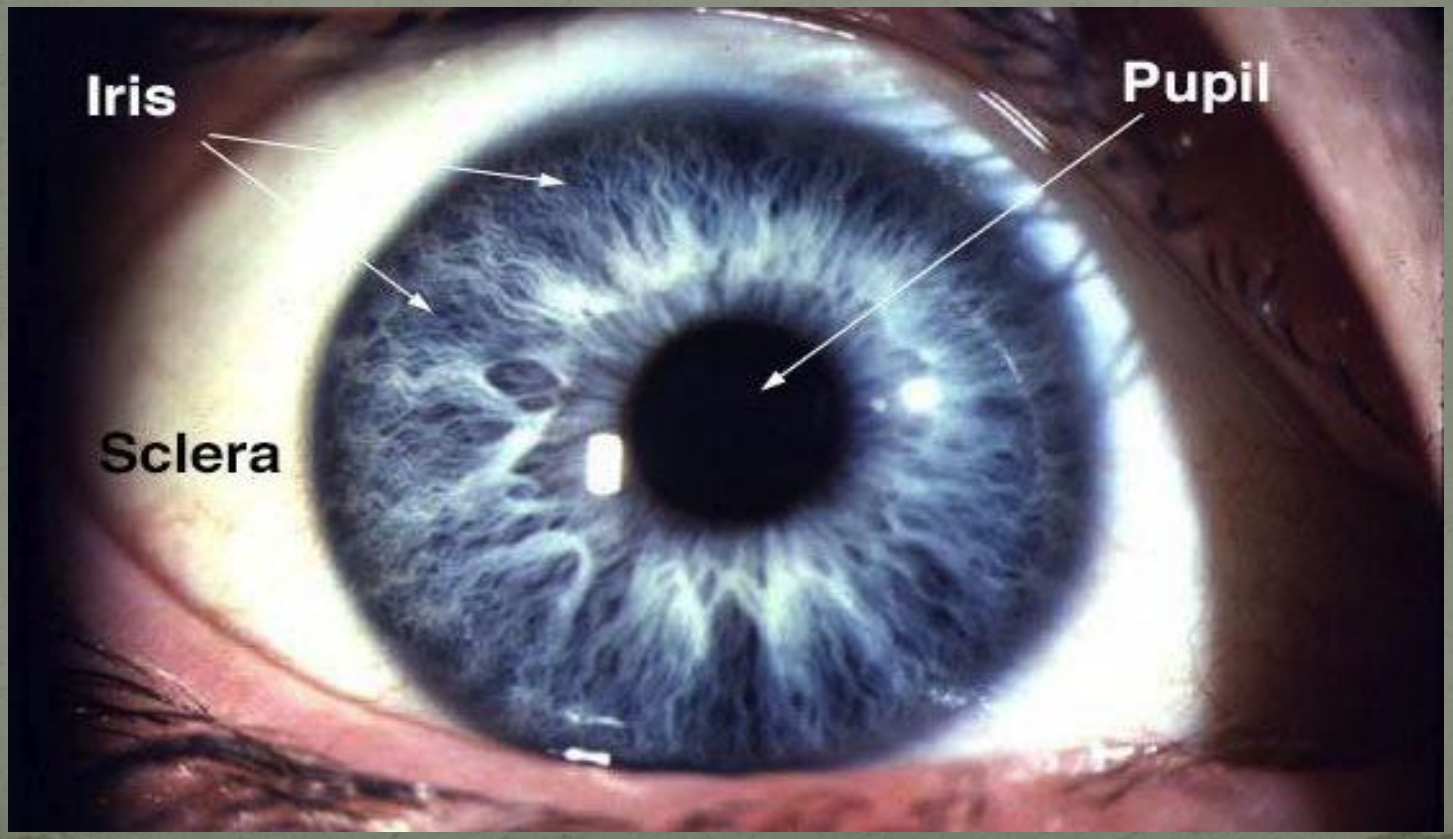
- Orbit – mechanical effect of mass, haemorrhage
- Muscle – fibrosis, inflammation, thyroid eye disease
- Neuro-muscular Junction Blocking – Myasthenia Gravis
- Nerve – Nerve Palsy (6^{th} nerve palsy), Mis-wiring of nerve (Duane's Syndrome)
- False-Locating Signs in Raised Intracranial Pressure – Bilateral Lateral Rectus Palsy
- Brainstem – Gaze Palsy

Part III Light Transmission

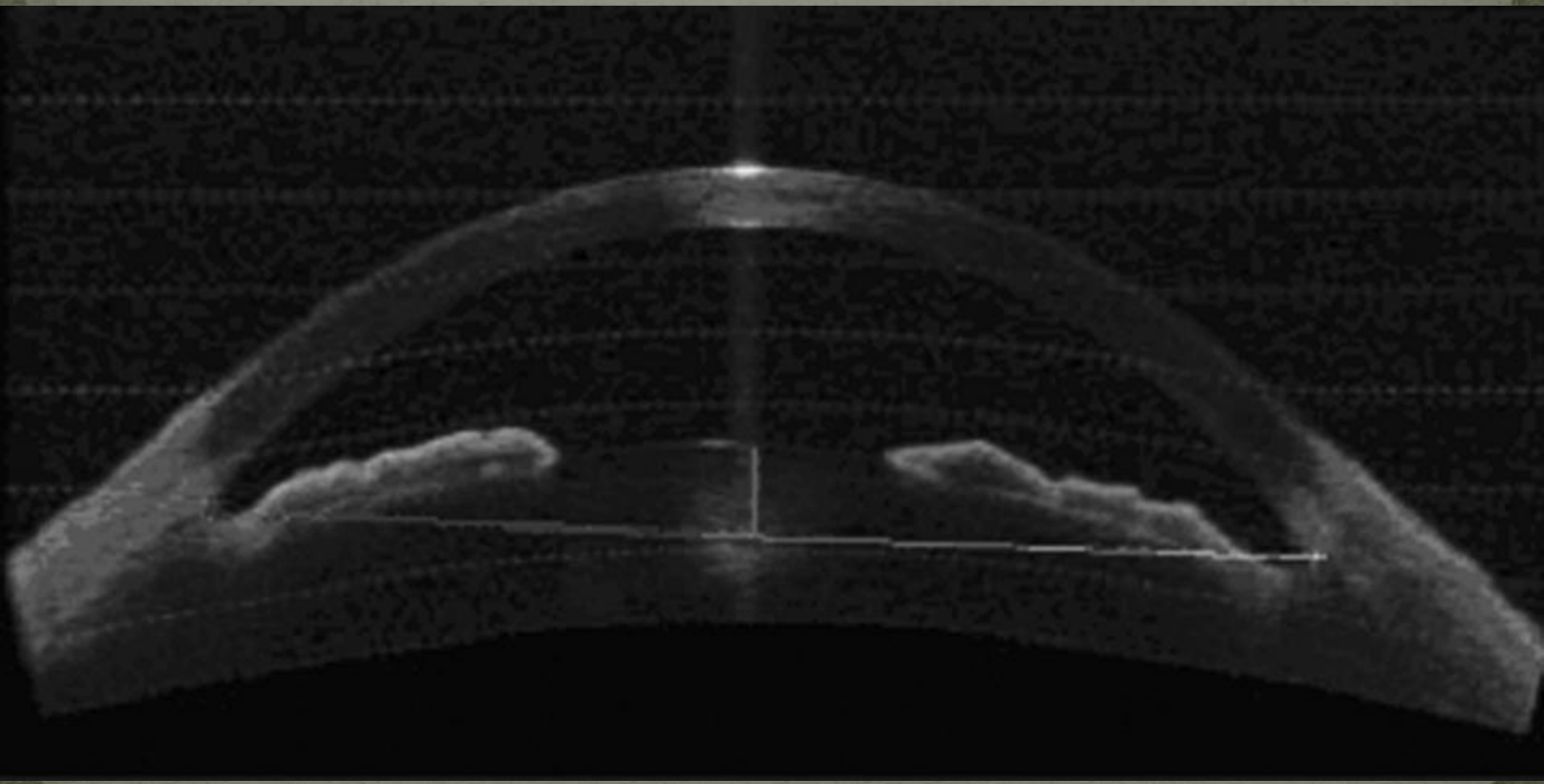

cornea
iris
conjunctiva
aqueous humor
ciliary body
lens
rectus tendon
zonule fibers
ora serrata
optic axis
visual axis
vitreous humor
pigment epithelium
retina
sclera
choroid
lamina cribosa
disc
fovea
macula lutea
nerve
sheath
section of human eye

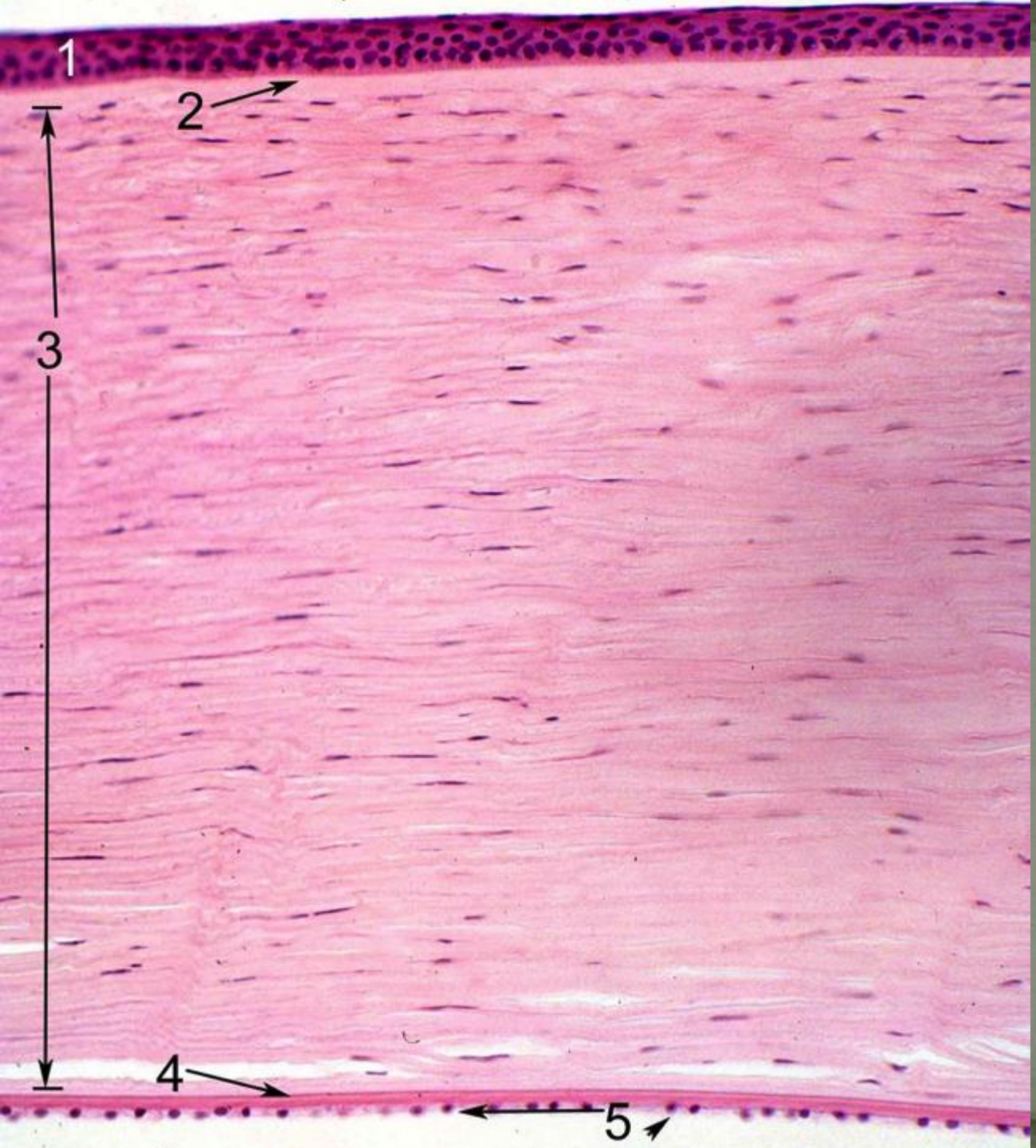
External Eye

- Cornea
- Conjunctiva



Optical Coherency Tomography





5 Layers of Cornea

1 Epithelium

2 Bowman's Membrane

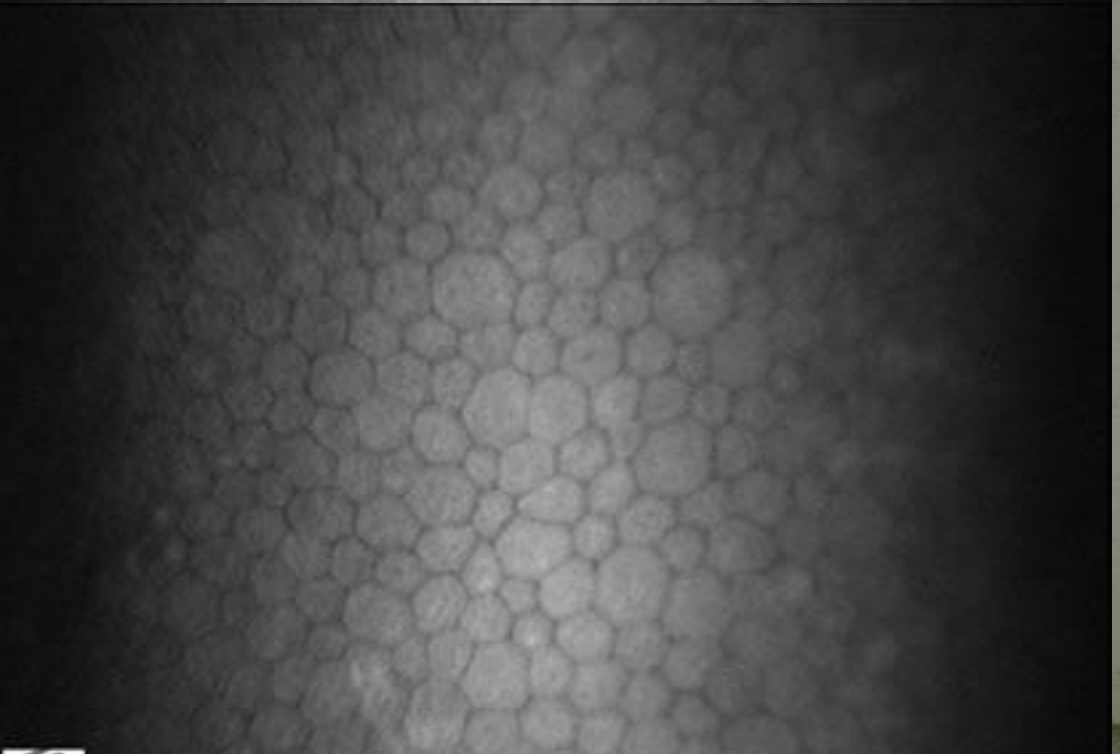
3 Stroma – maintains transparency

4 Descemet Membrane

5 Endothelium – virtually no regeneration, responsible for pumping out stromal fluid

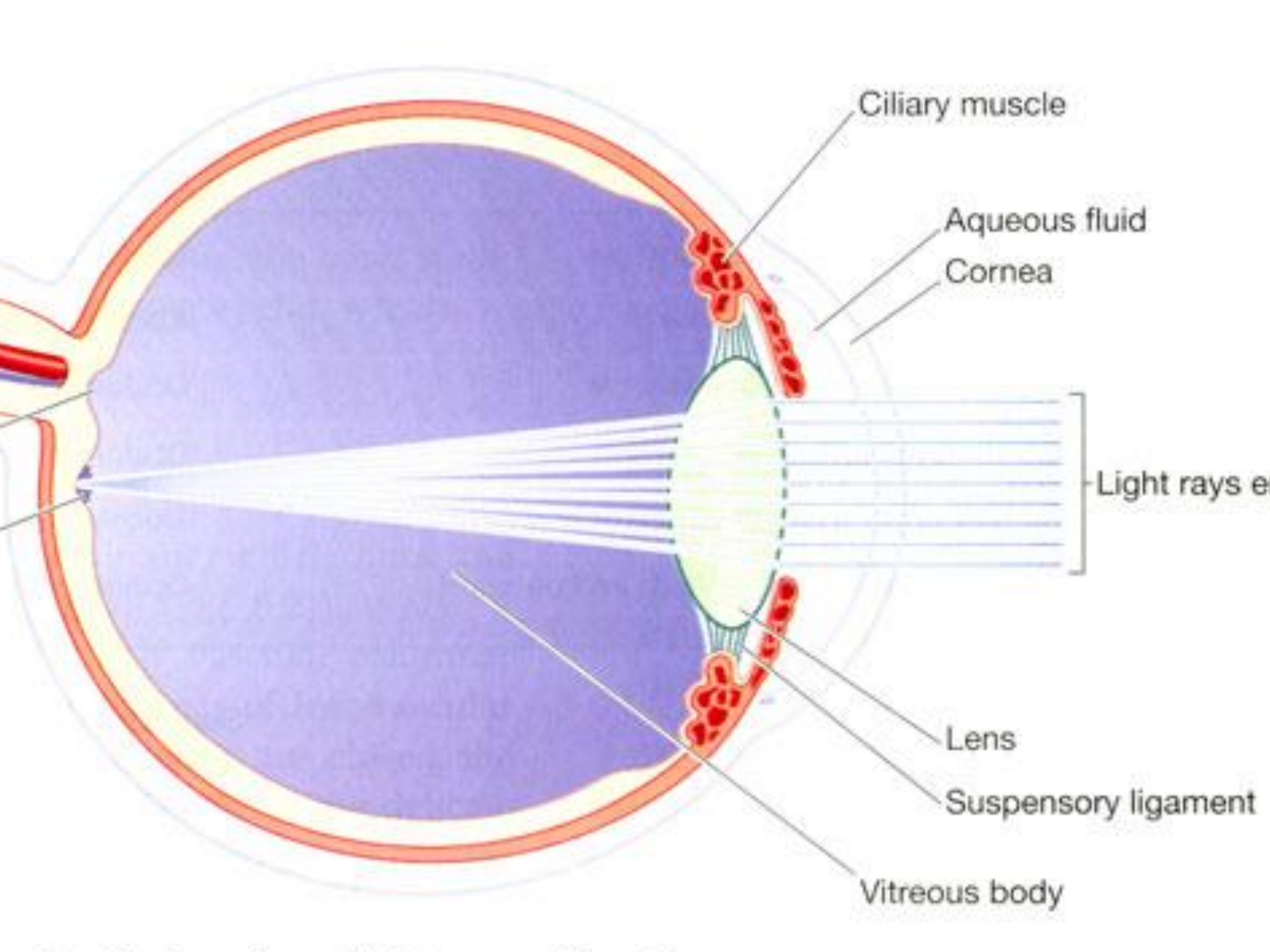
Cornea Functions

- Transparency – Regularity of Stromal Layer – Order of Regularity much less than wavelength of visible light – 390 - 750 nm.
- Refraction – Bends light, converges parallel ray into convergent ray – 2/3 of refraction power
- Physical Barrier
- Infection Barrier



Confocol Microscopy

- Regular Healthy Corneal Endothelial Cells
- Irregular Unhealthy Corneal Endothelial Cells


Ciliary muscle
Aqueous fluid
Cornea
Light rays e
Lens
Suspensory ligament
Vitreous body

Oculus Optikgeräte GmbH
Münchholzhäuser Str. 29
35582 Wetzlar
Tel. (0641) 20 05-0
Fax (0641) 20 05-255
www.oculus.de

OCULUS

OCULUS · PENTACAM

Last Name:
First Name:
ID:
Date of Birth: Eye: Right
Exam Date: Time: 11:45:41
Exam Info:

Cornea Front

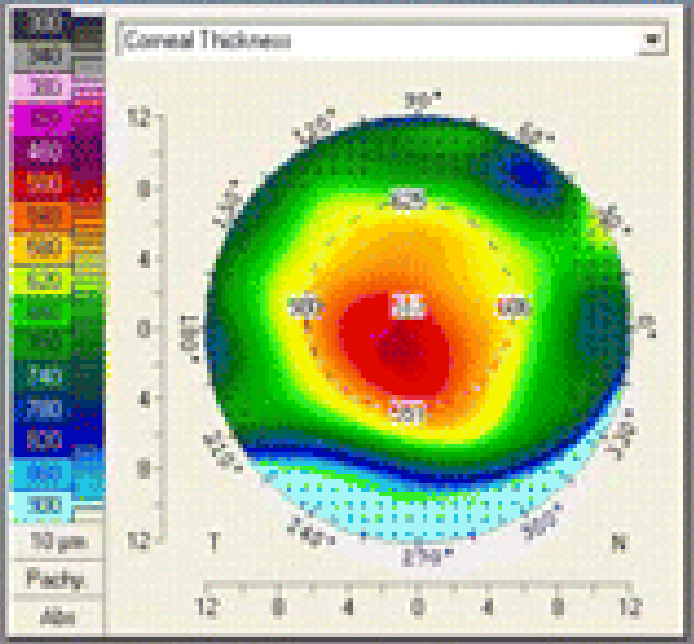
Rfl: 7.81 mm 48.2 D
Rv: 8.31 mm 40.6 D
Rm: 7.65 mm 44.1 D
QS: OK Axis: 75.5° Astig: +7.5 D
ecc: 0.13 Rper: 7.73 mm Rasm: 8.40 mm

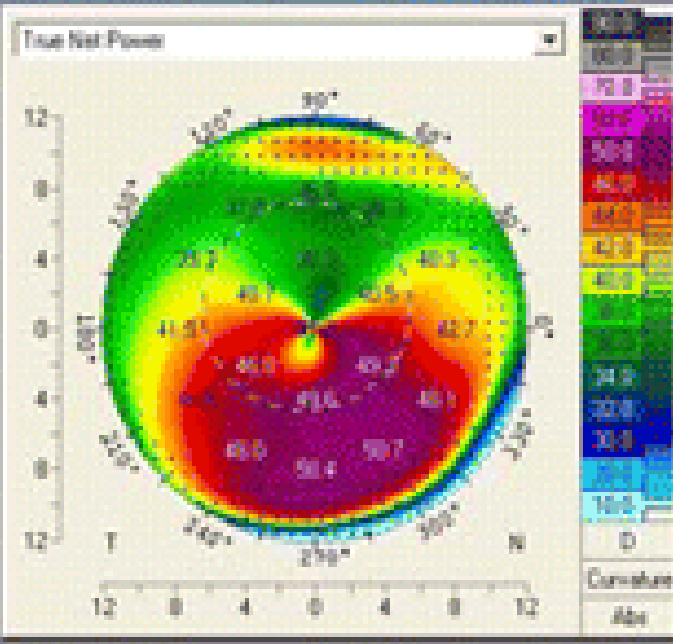
Cornea Back

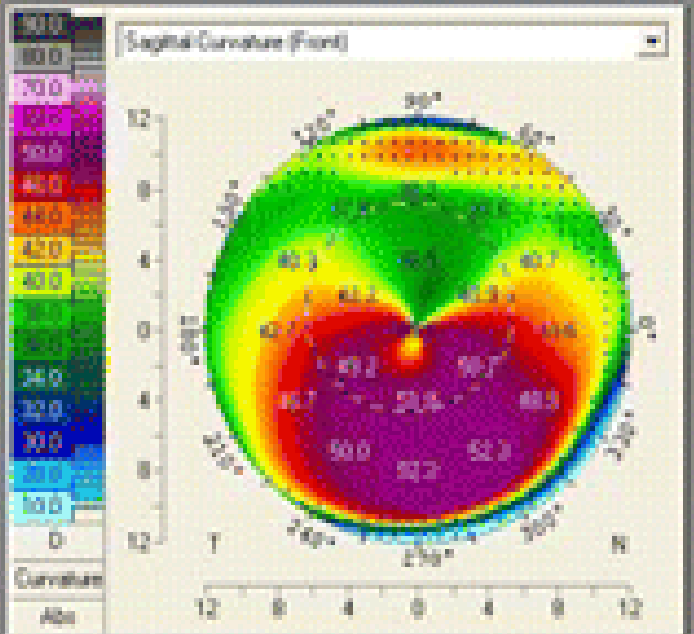
Rfl: 5.71 mm
Rv: 6.93 mm
Rm: 6.32 mm
QS: OK Axis: 79.8° Astig: 1.2 D
ecc: 0.29 Rper: 6.56 mm Rasm: 4.65 mm

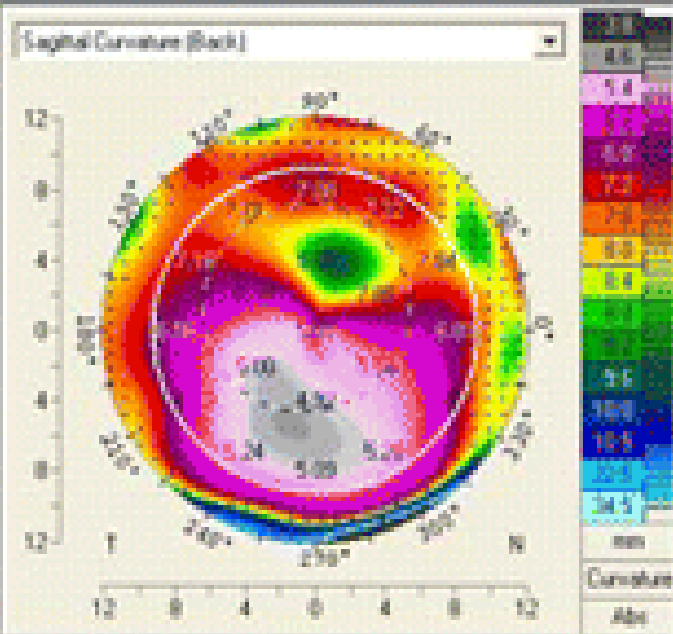
	Pachy	x[mm]	y[mm]
Pupil Center:	517 µm	-0.25	+0.63
Pachy Apex:	502 µm	0.00	0.00
Thinnest Locat.:	488 µm	-0.68	-0.41

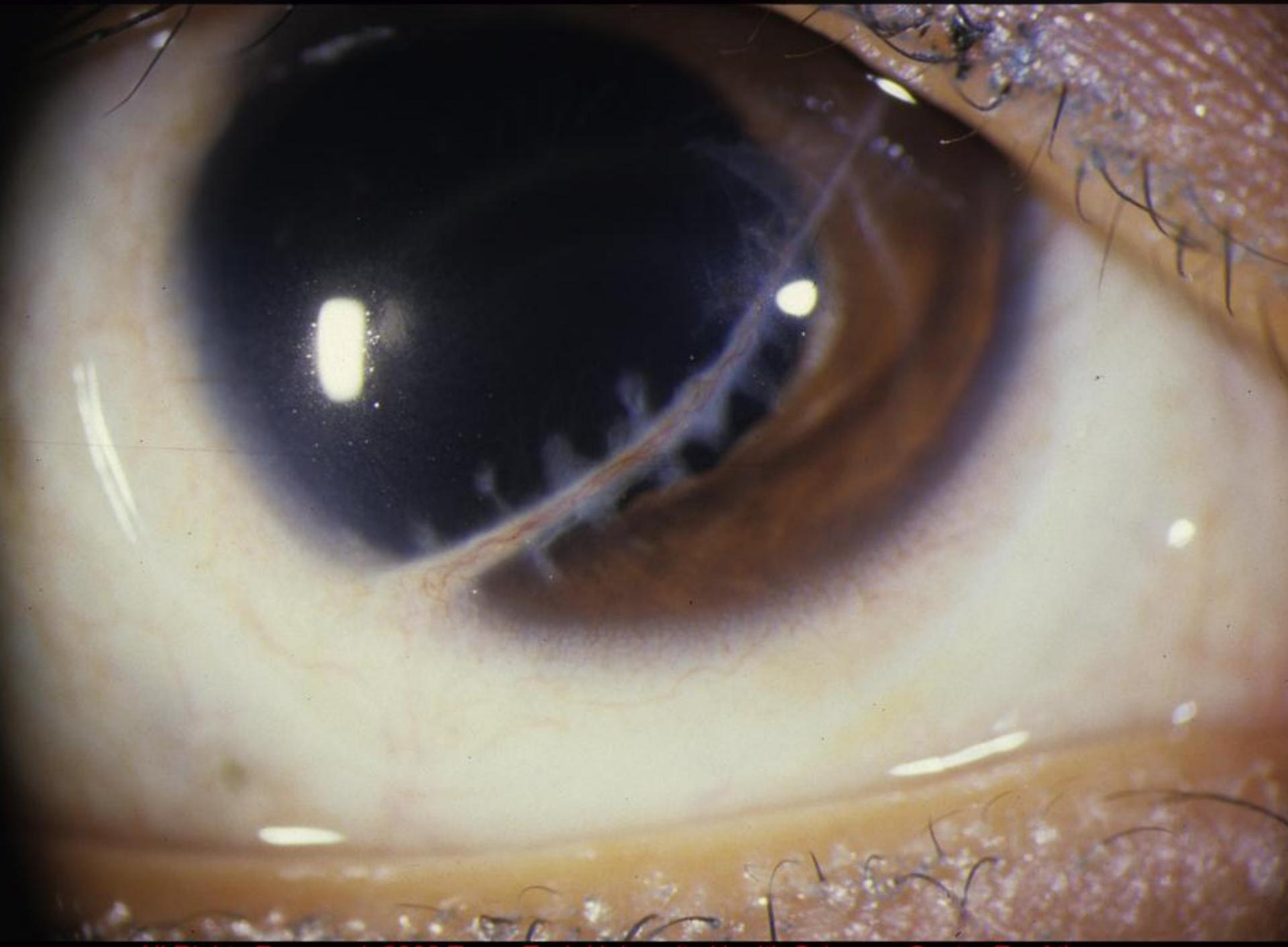
Cornea Volume: 58.6 mm³ KPD: +1.8 D
Chamber Volume: 187 mm³ Angle: 22.9°
A. C. Depth (Int.): 3.11 mm Pupil Dia: 5.84 mm
Enter IOP: IOP(cor): Lens Th.: 3.51 mm







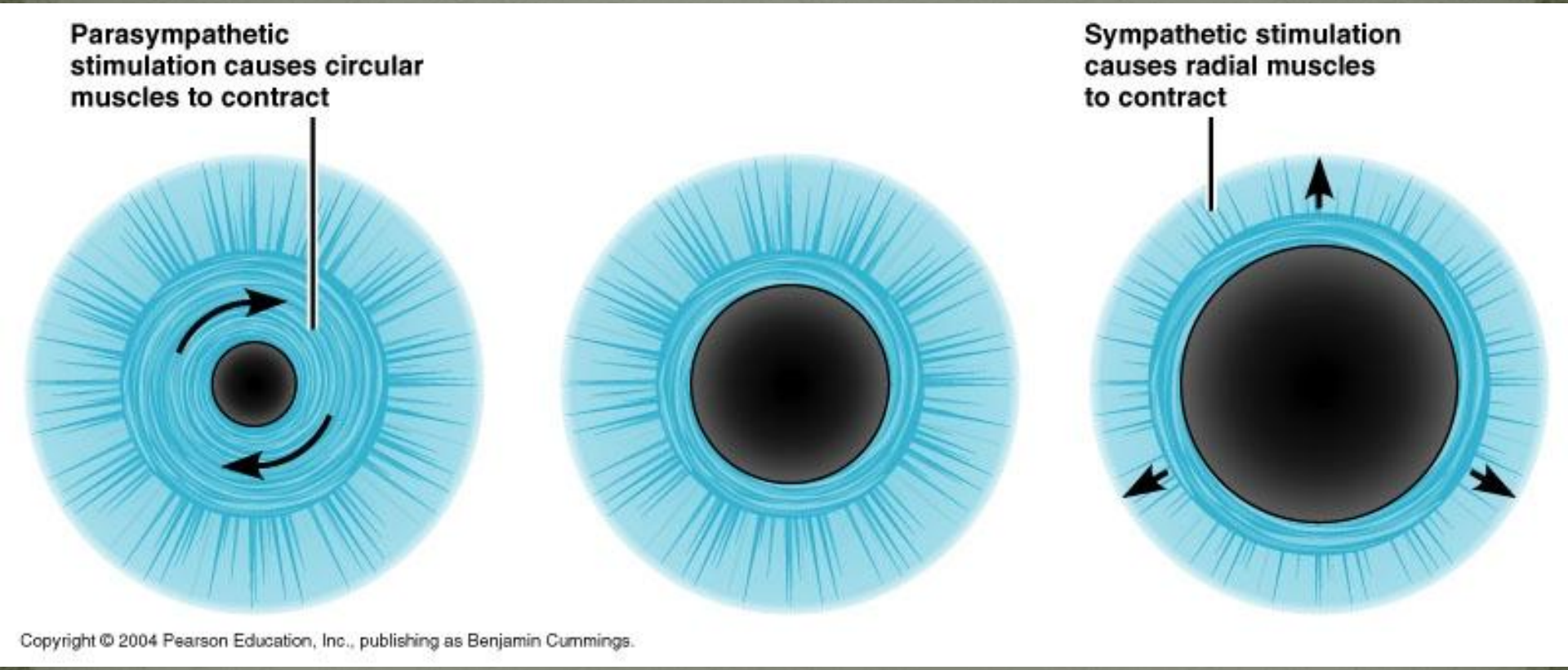




What does the pupil do?

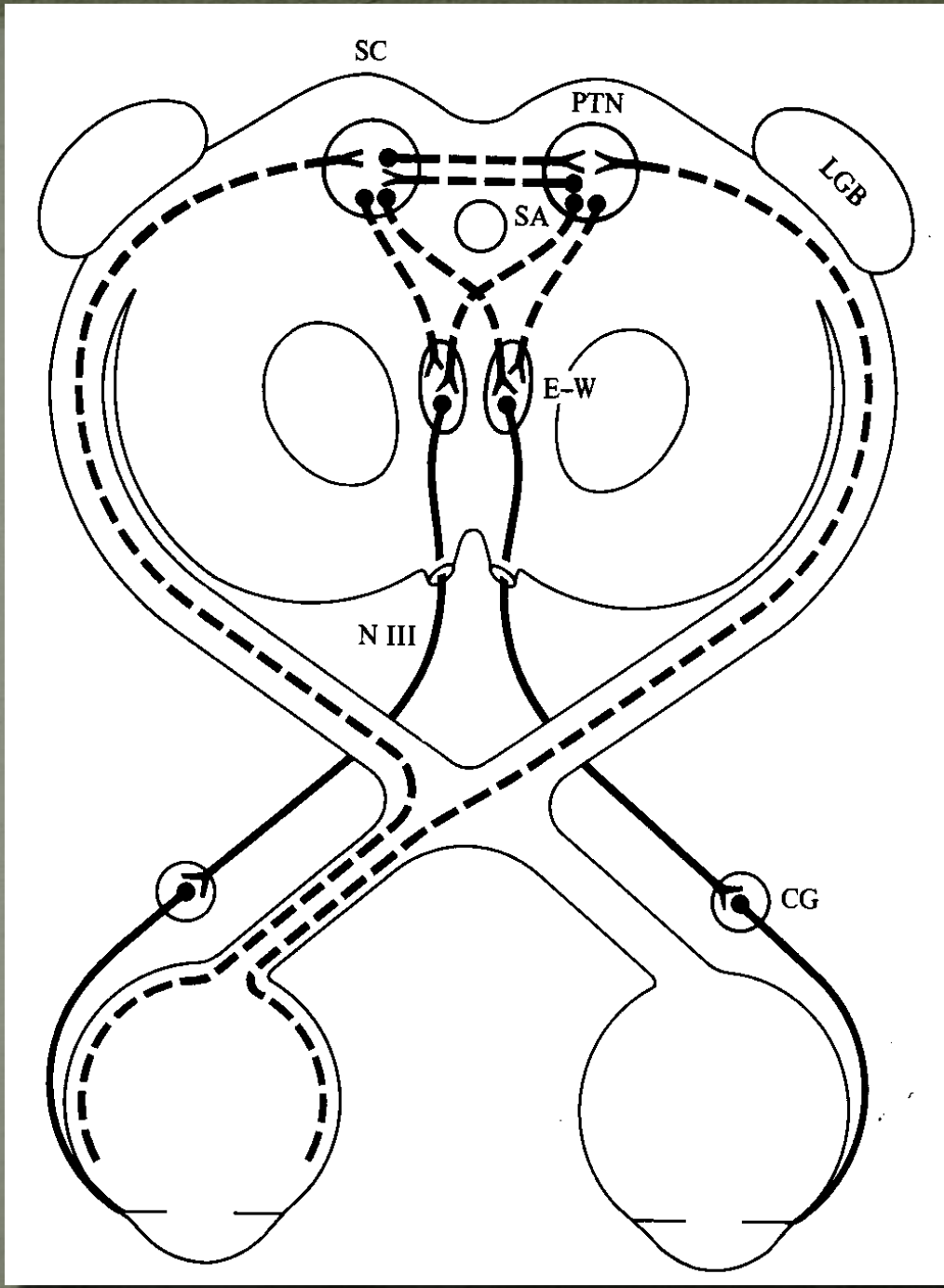
- Regulates light input to eye (but NB less than 2 log unit change) Feedback Loop
- In light:
  - decrease spherical aberrations and glare
  - increase depth of focus
  - reduce bleaching of photo-pigments
- In dark:
  - enlarge visual field
  - lower threshold for light perception

Autonomic Control of Pupil



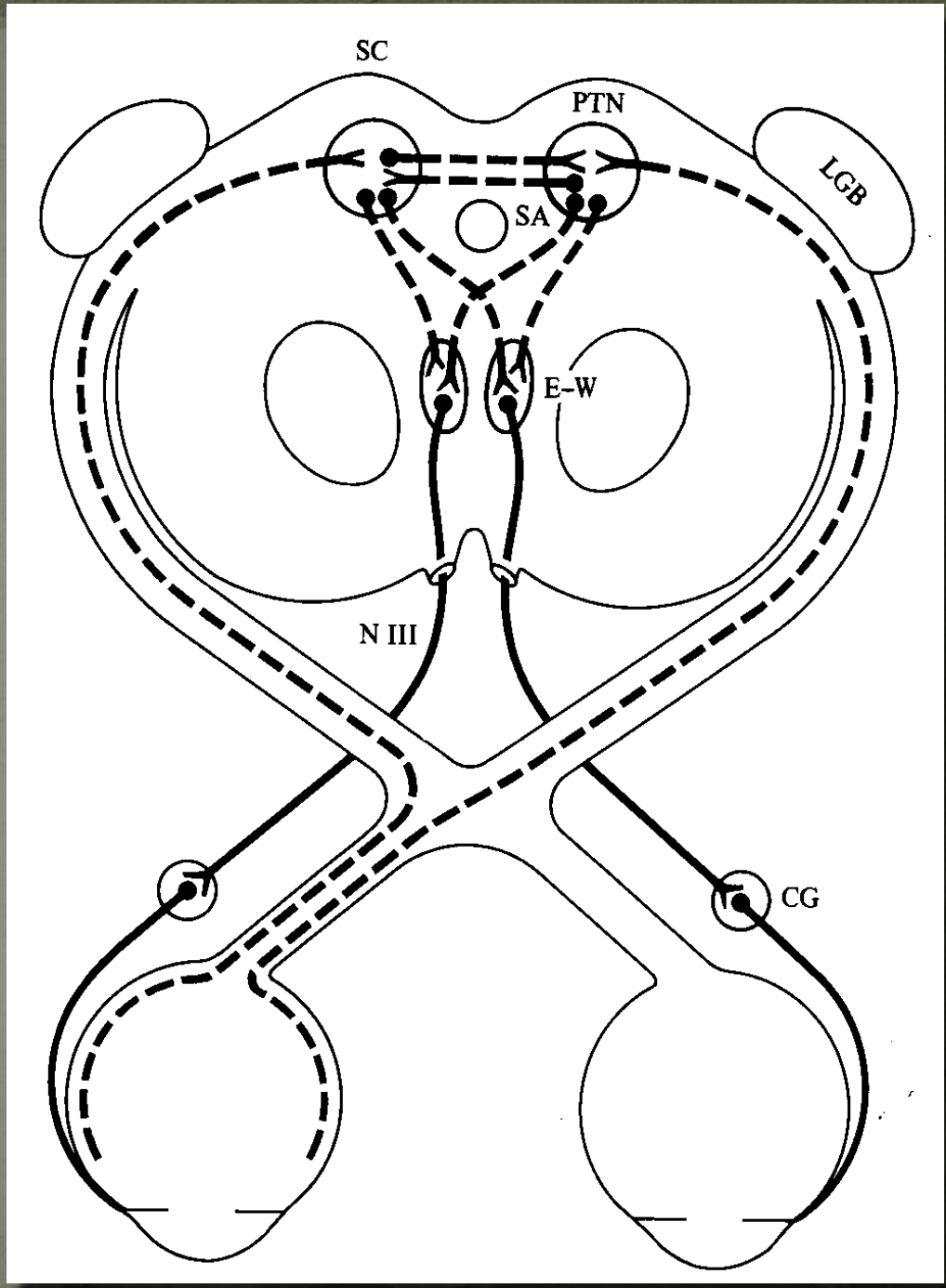
Afferent Light Pupil Reflex

- Afferent pathway
  - Rod and cone photoreceptors
  - Pupil-specific ganglion cells
  - Exit at posterior third of optic tract
  - Three partial crossings



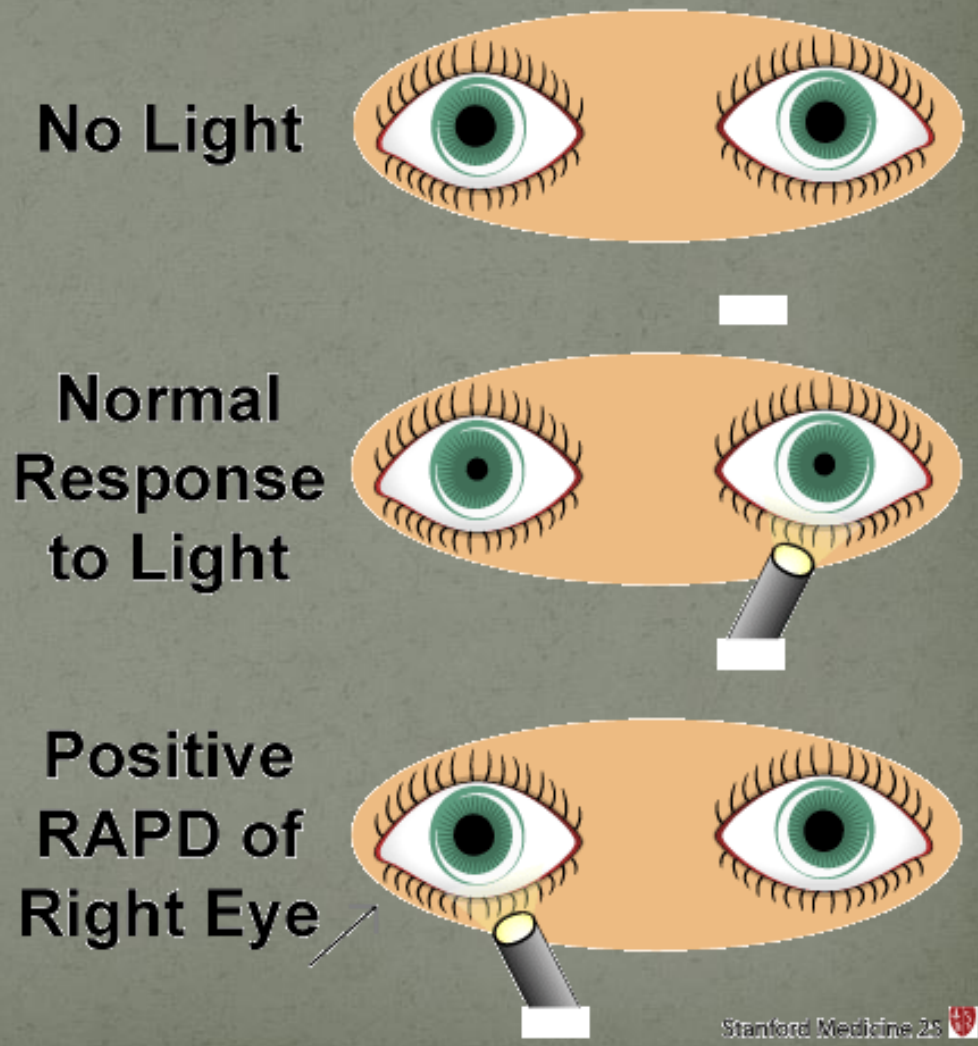
Efferent Light Pupil Reflex

- Efferent pathway
  - Two neurons
  - Edinger-Westphal nucleus specific to sphincter
  - Synapse at ciliary ganglion
  - Exit midbrain at interpeduncular fossa



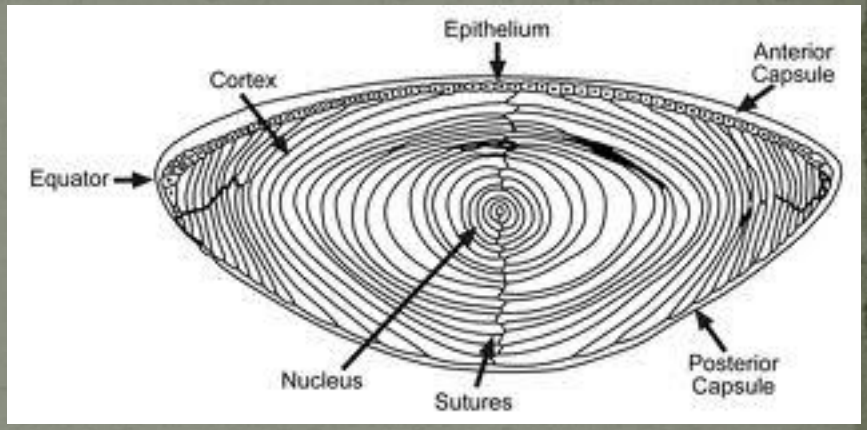
Reflex Pathways: Pupil Light Reflex

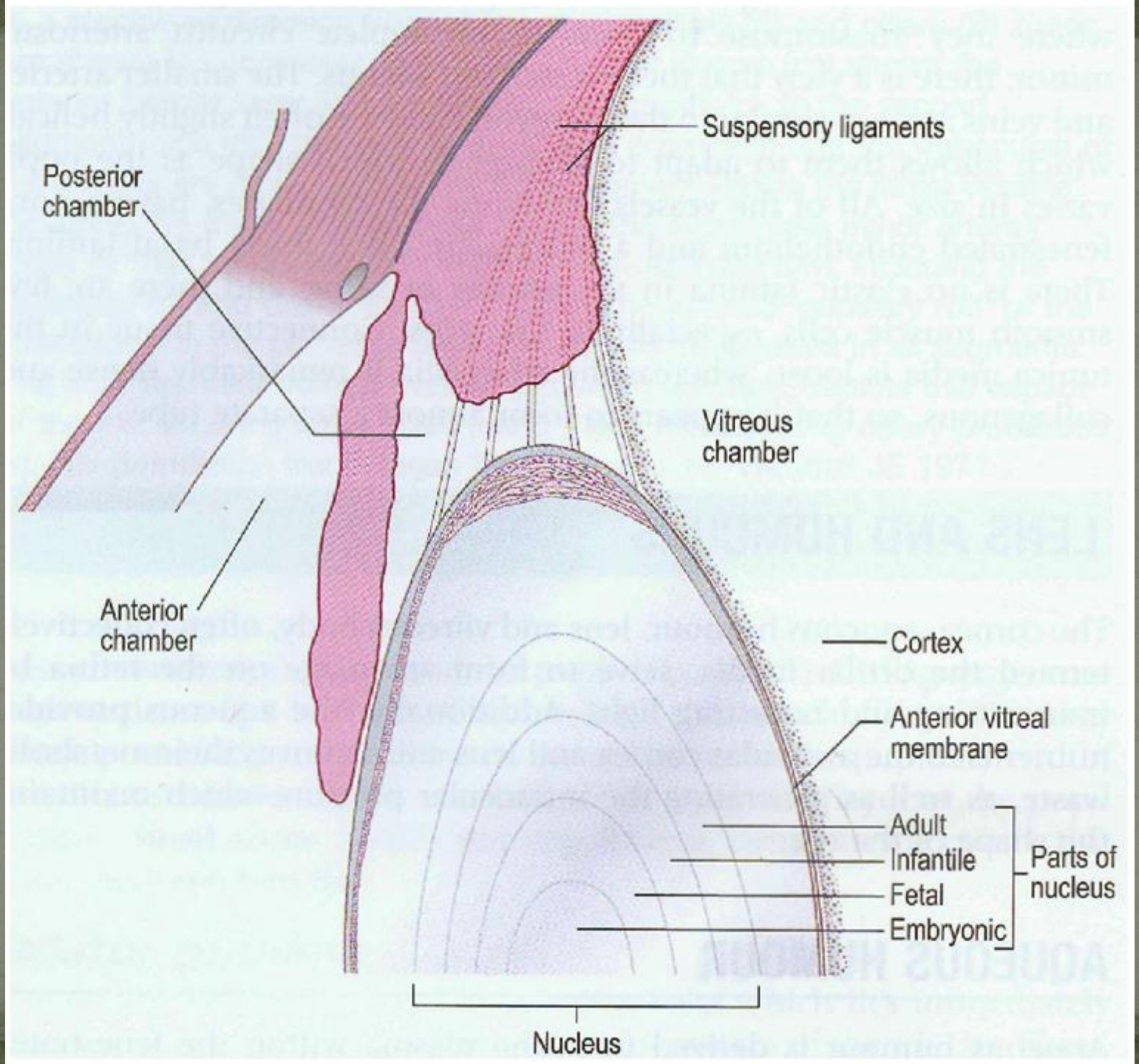
- Unilateral afferent defect
- Unilateral efferent defect: unequal pupil size (anisocoria)



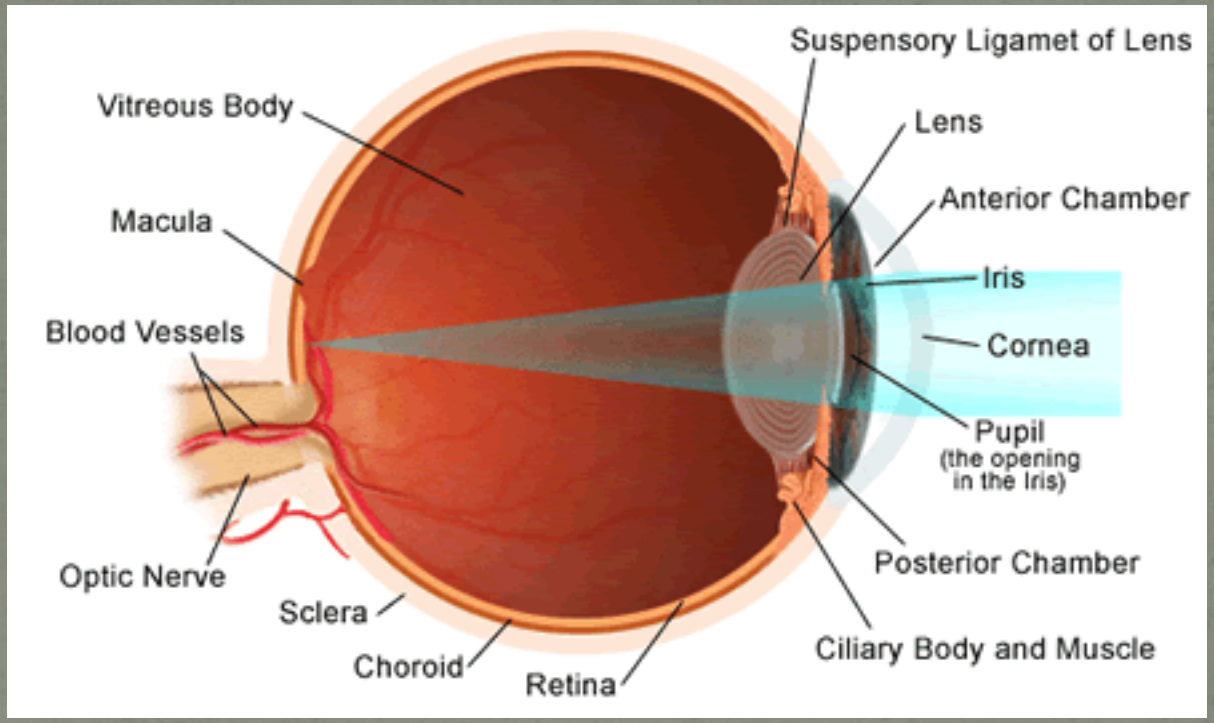
Lens Anatomy

- Anatomy
  - Outer acellular capsule
  - Epithelium
  - Inner elongated cells - lens fibres
- Transparent
  - No blood vessels
  - Orderly arrangment of fibres
  - Small refractive. index differences between components

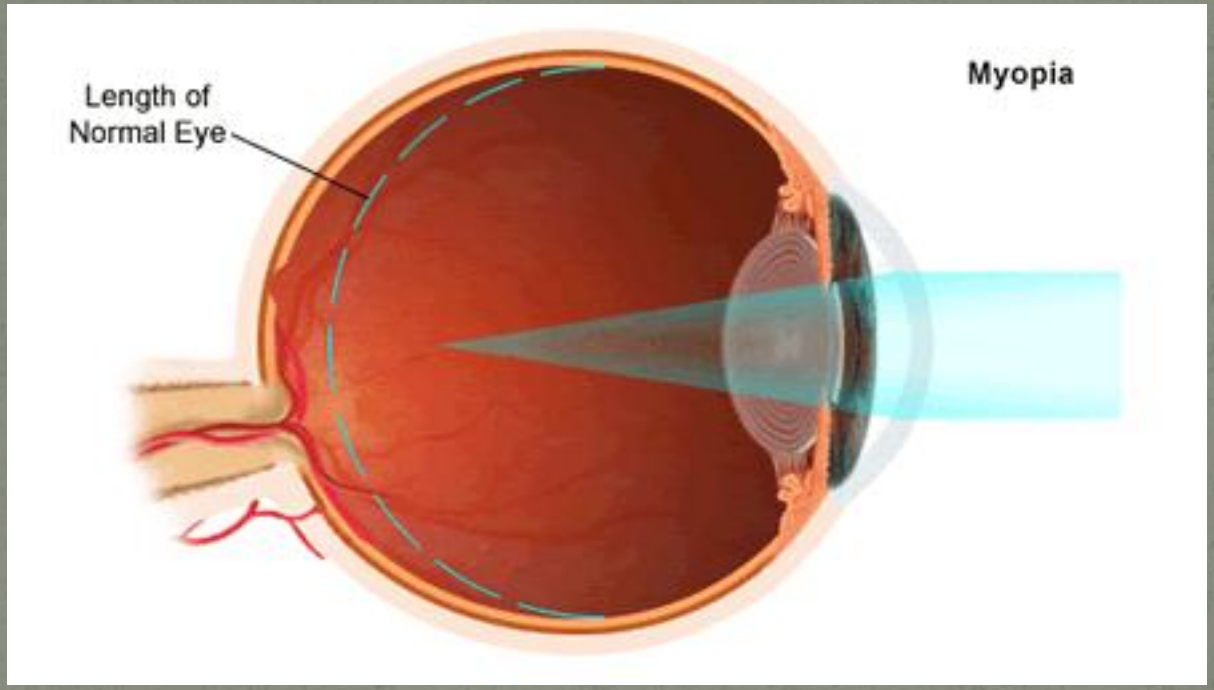



Suspensory ligaments
Posterior chamber
Vitreous chamber
Anterior chamber
Cortex
Anterior vitreal membrane
Adult
Infantile
Fetal
Embryonic
Parts of nucleus
Nucleus

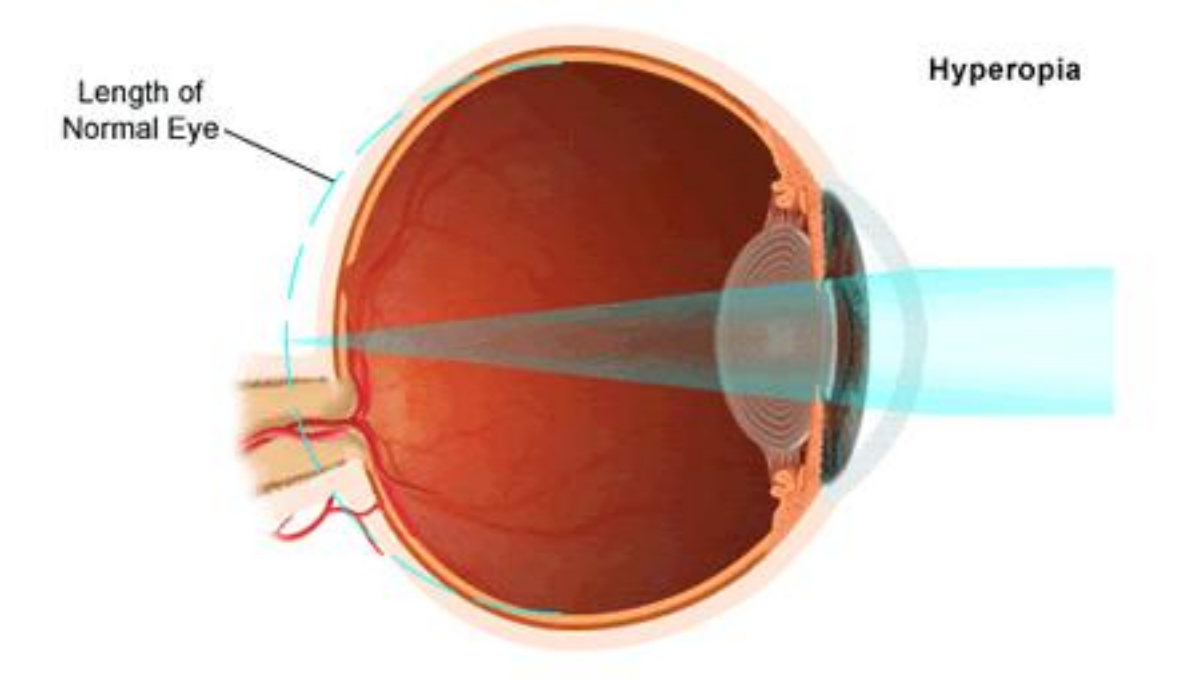
Emmetropia


Suspensory Ligamet of Lens
Vitreous Body
Lens
Anterior Chamber
Macula
Iris
Blood Vessels
Cornea
Pupil
(the opening
in the Iris)
Posterior Chamber
Optic Nerve
Sclera
Ciliary Body and Muscle
Choroid
Retina

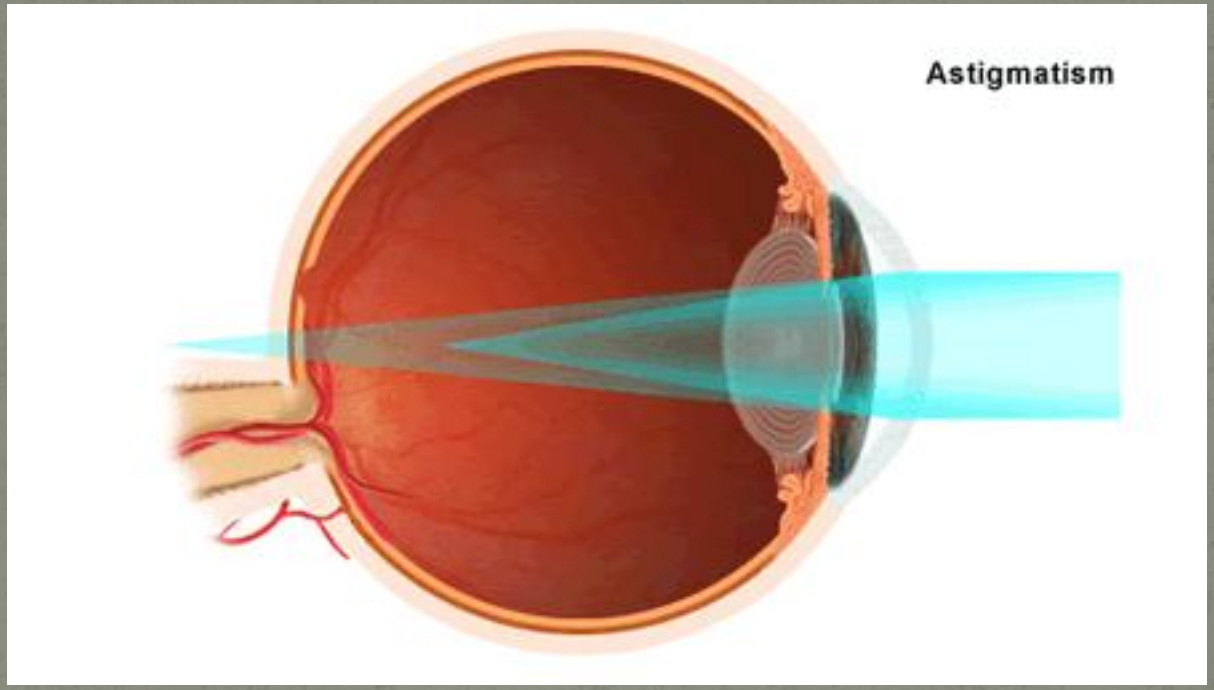
Myopia – Short Sighted



Hyperopia – Long Sighted

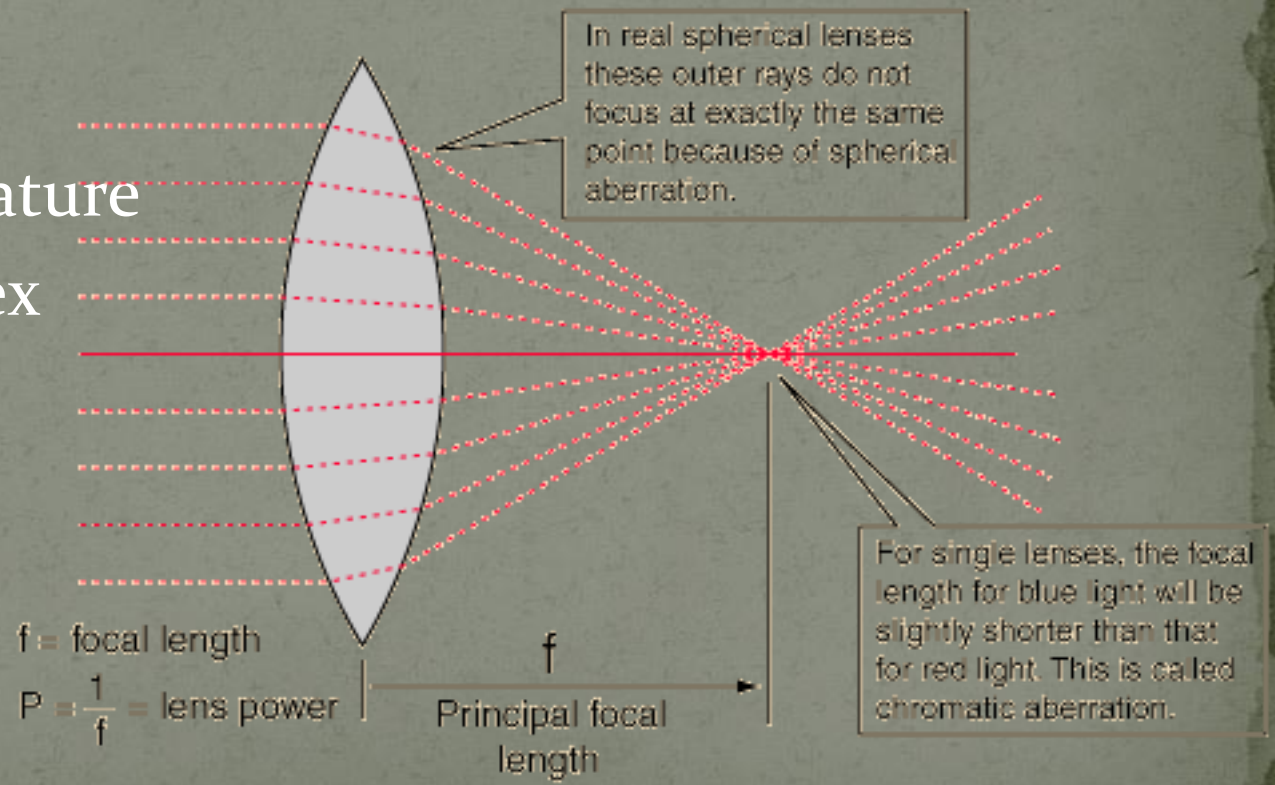


Astigmatism



Dioptic Power

- 1D – power to converge parallel ray of light at 1 meter ahead
- Interface Curvature
- Refractive Index Difference



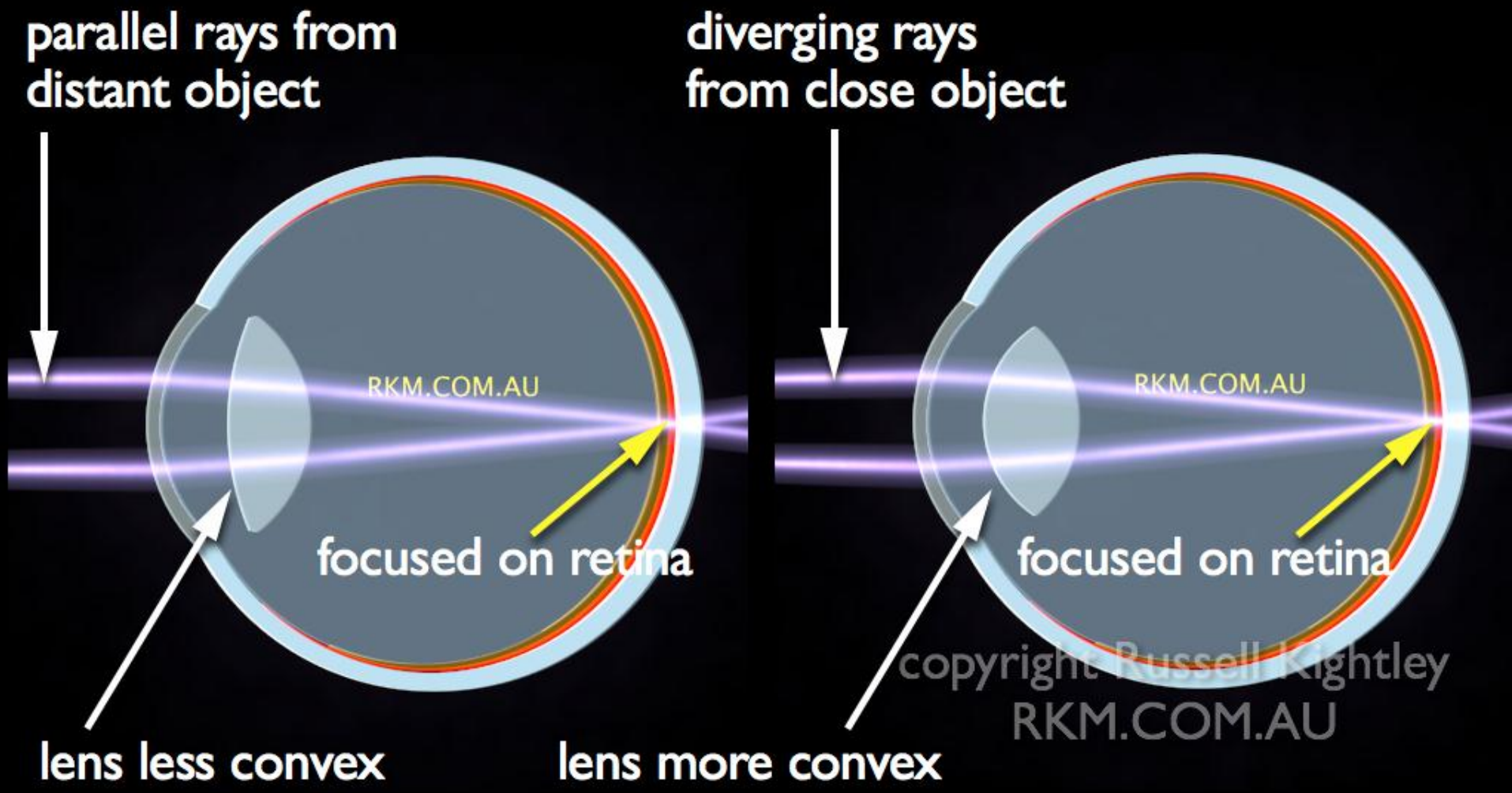
The Near Response

- The Near Response / Complex / Triad
  - Pupillary miosis *(sphincter pupillae)*
  - Convergence *(medial rectus)*
  - Accommodation *(ciliary muscle)*
- Common efferent pathway (*3rd Nerve*)
- Disassociation from light reflex
  - Argyll-Robertson Pupil

Near Response

- The Near Response / Complex / Triad
  - Pupillary miosis (sphincter pupillae)
  - Convergence (medial rectus)
  - Accommodation (ciliary muscle)
- Common efferent pathway (3rd Nerve)
- Disassociation from light reflex
  - Argyll-Robertson Pupil

EYE: accommodation (focusing)

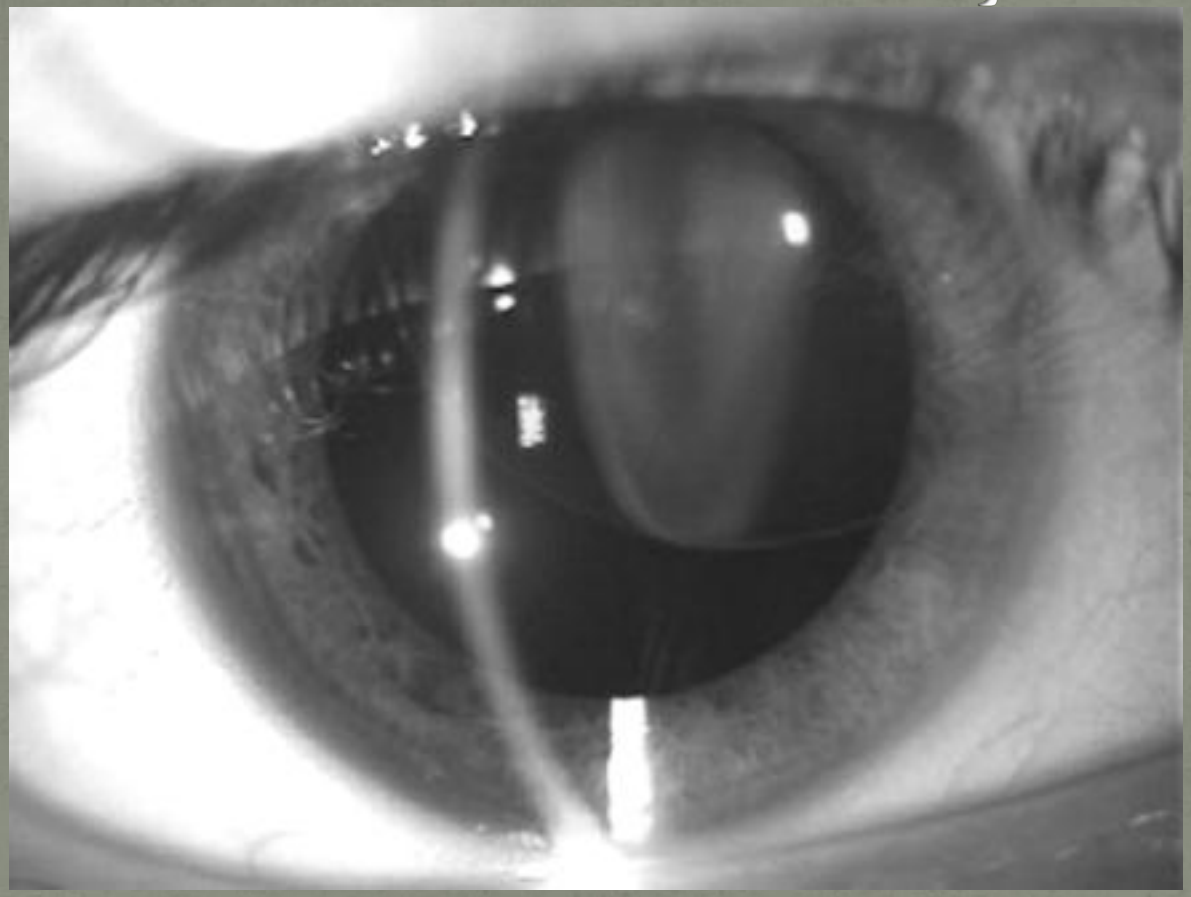


lens increases in convexity to focus rays from closer objects

Presbyopia

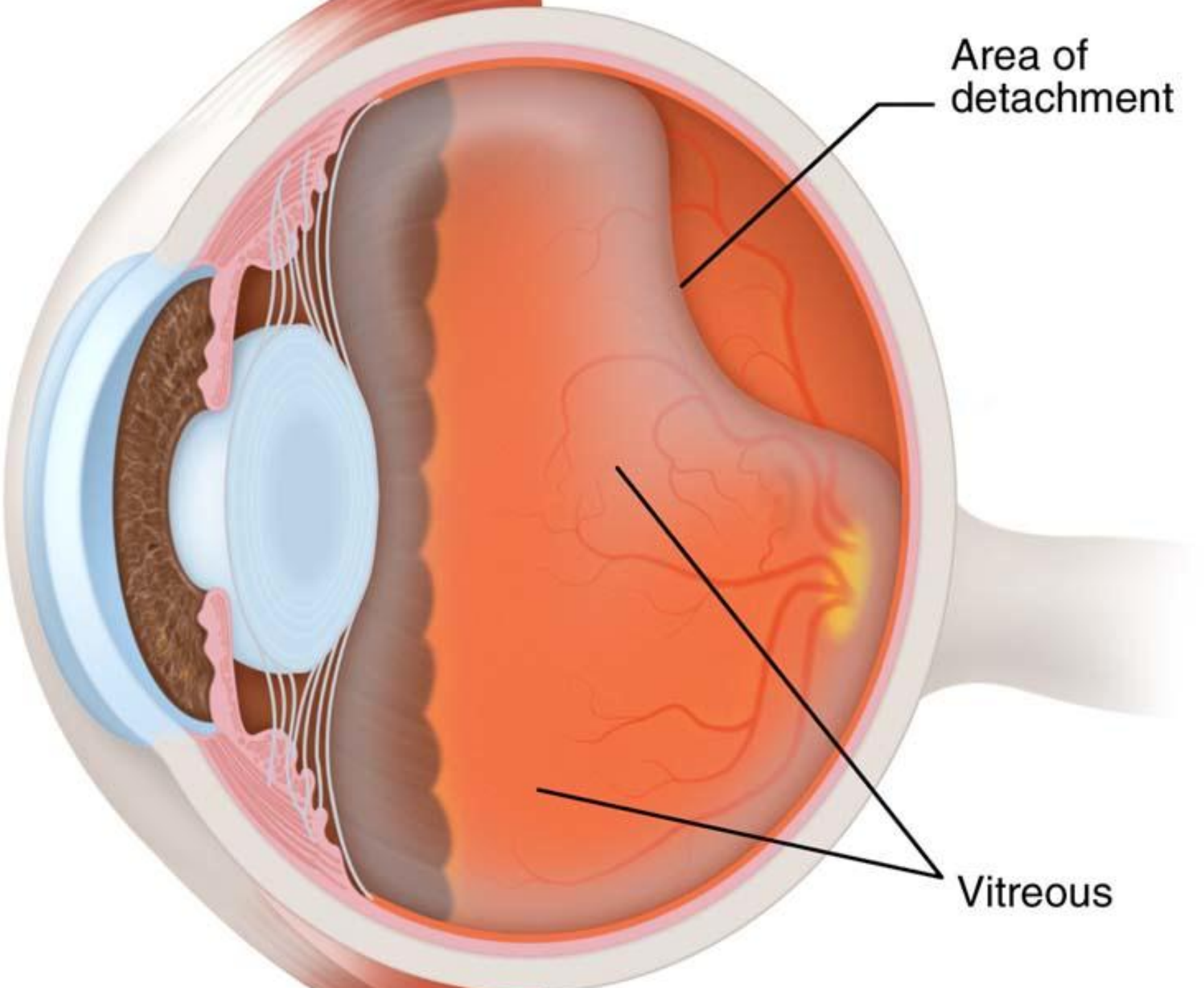
- Natural occurring loss of accommodation (focus for near objects)
- Onset from age 40 years
- Distance vision intact
- Corrected by reading glasses (converging lenses) to increase optical power of eye

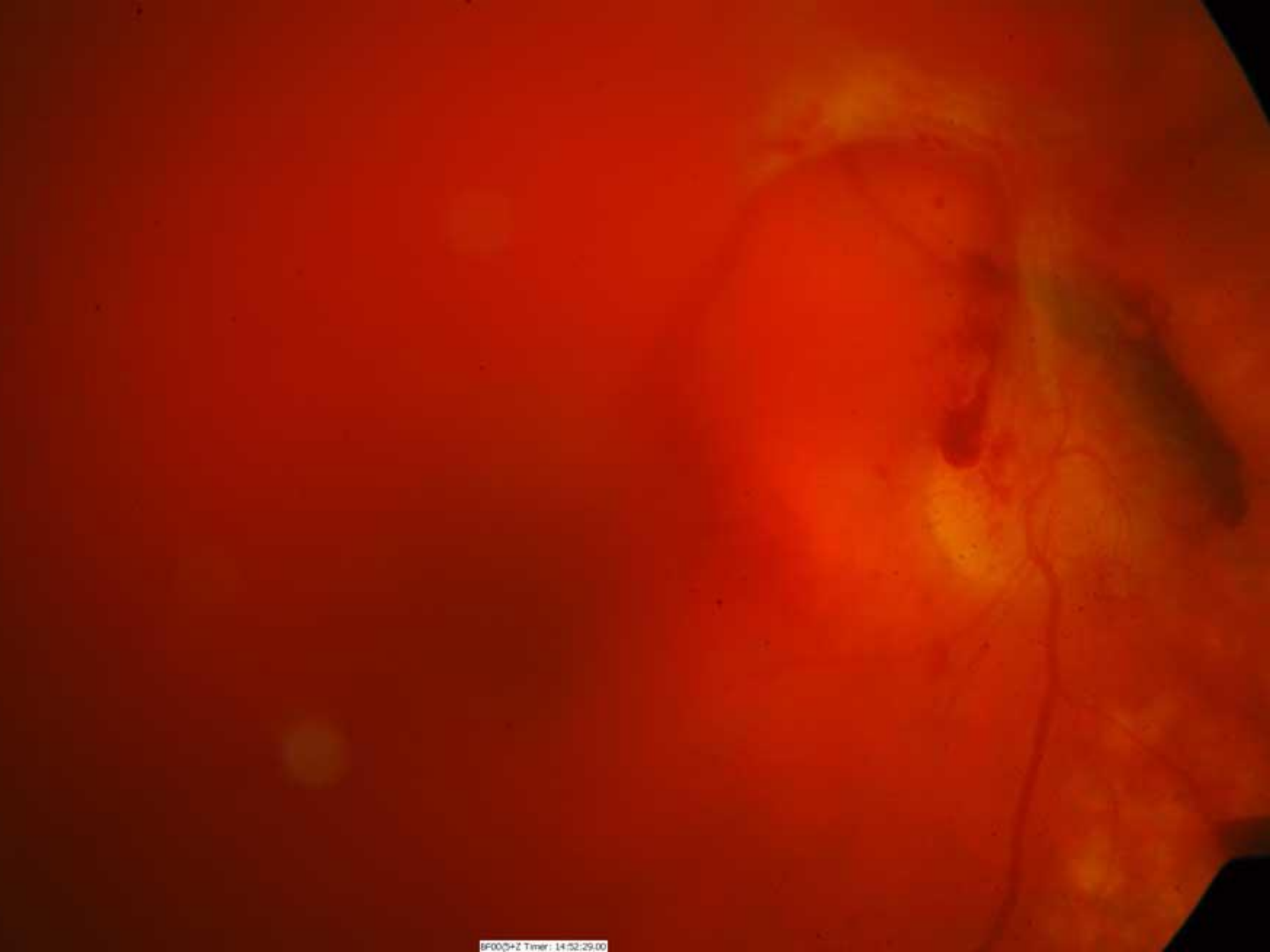
Lens Subluxation – Marfan's Syndrome



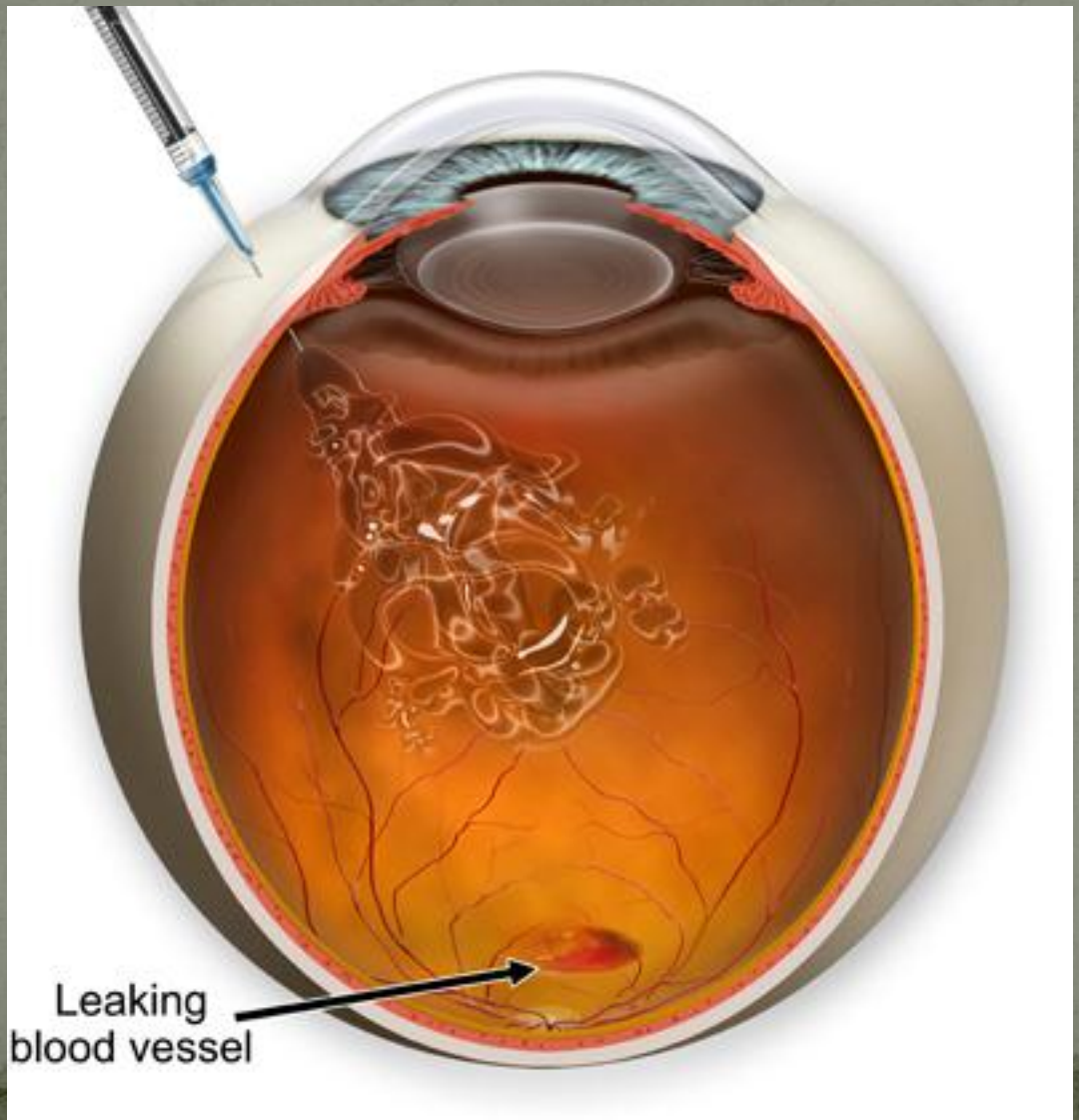
Vitreous

- Structure
  - 80% globe by volume
  - 90% water
  - Few cells (hyalocytes)
  - Structural protein: collagen
  - Hyaluronic acid gives gel properties
- Function
  - Transparency
  - Mechanical buffering
  - Passive transport/removal of metabolites


Area of
detachment
Vitreous


BP00@+Z Timer: 14:52:29.00

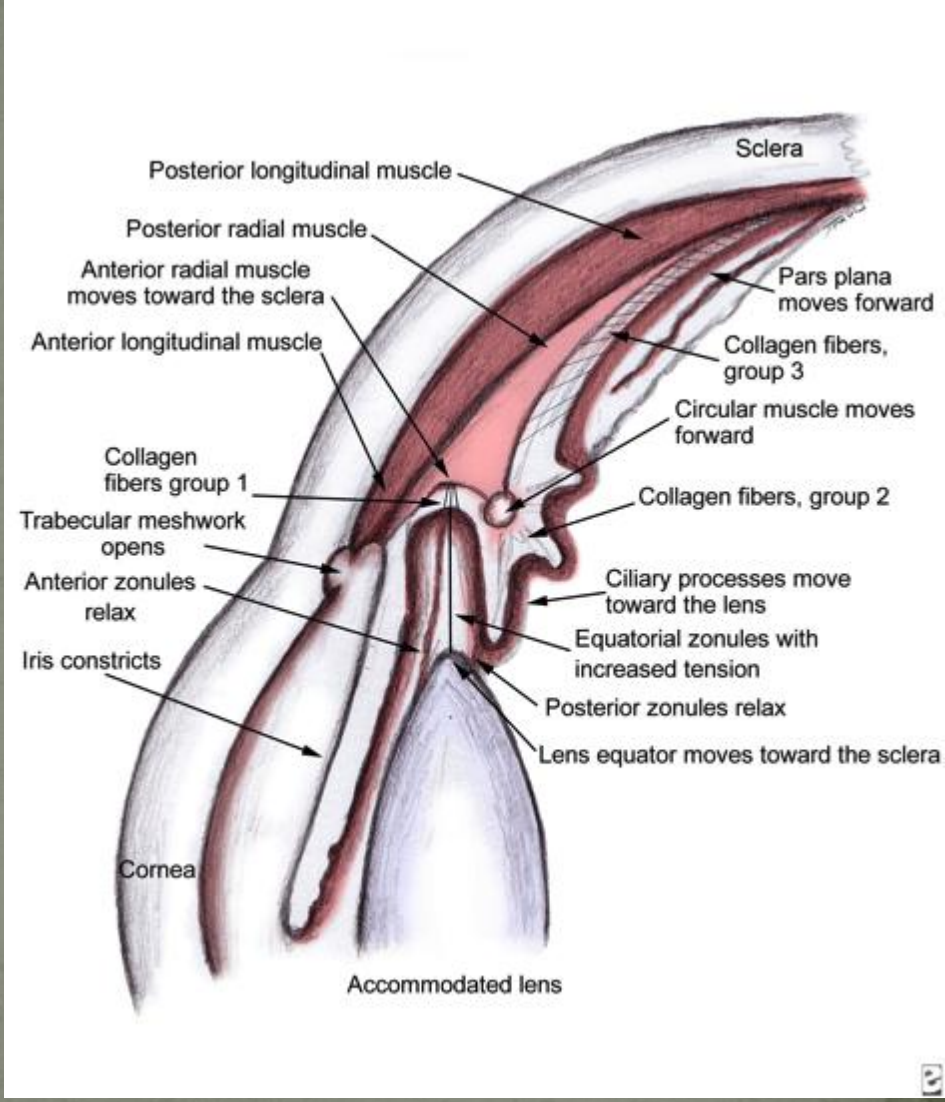
Intravitreal Injection



Part IV Circulation

Ciliary Body

- Structure
  - Smooth muscle
  - Ciliary processes
- Function
  - Aqueous humour formation
  - Support of zonule fibres
  - Accommodation

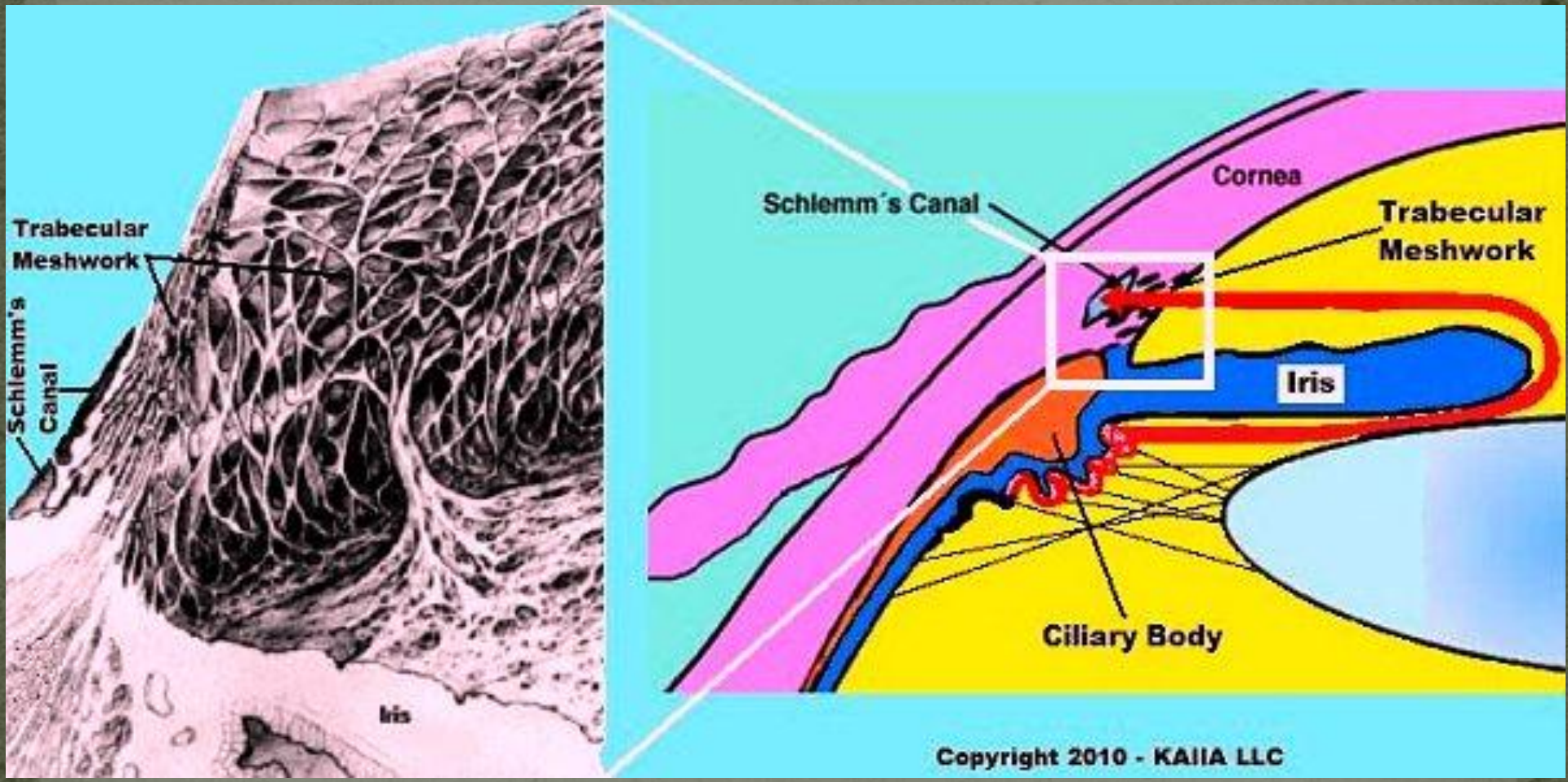


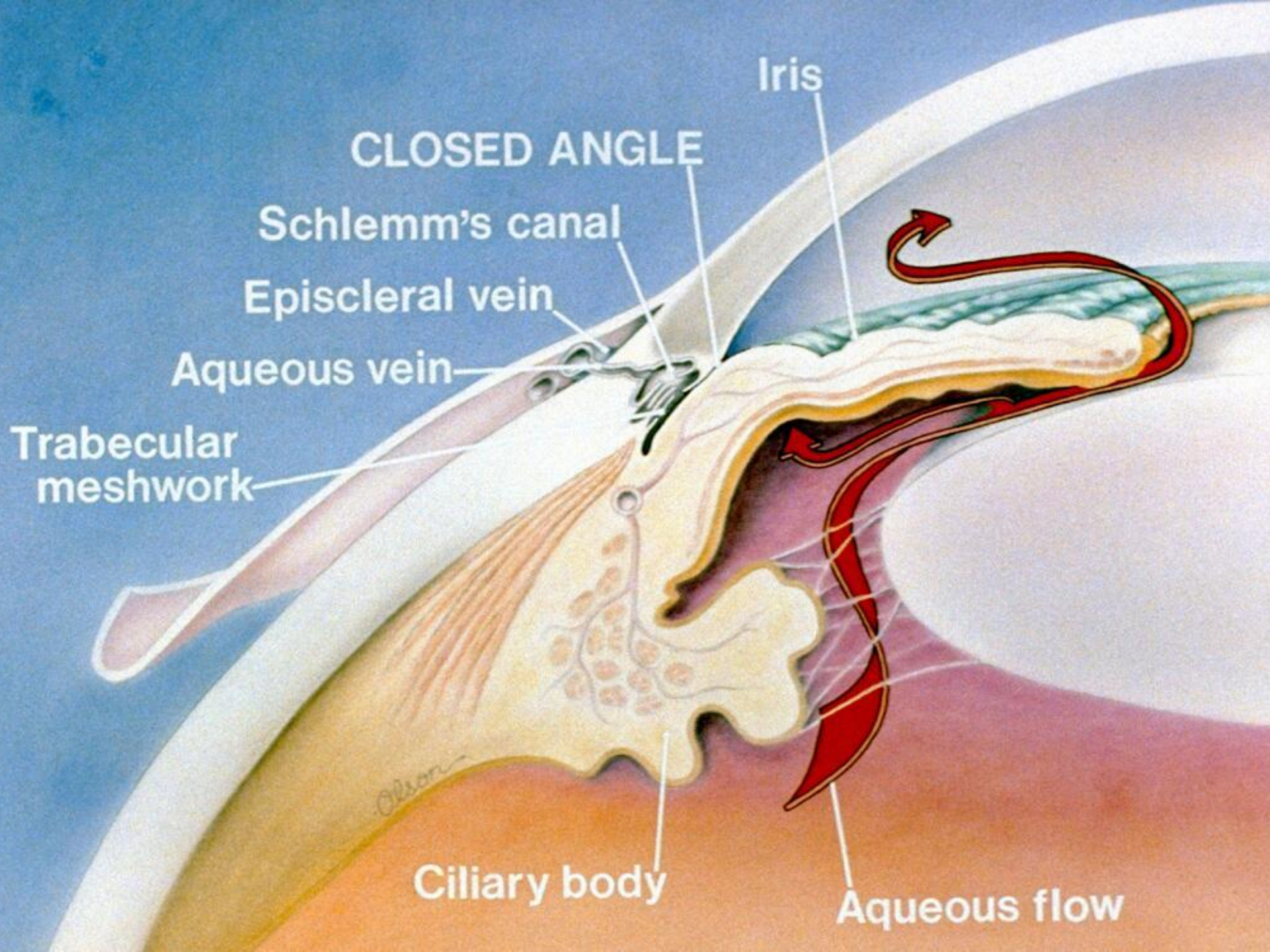

I
CB
Z
L

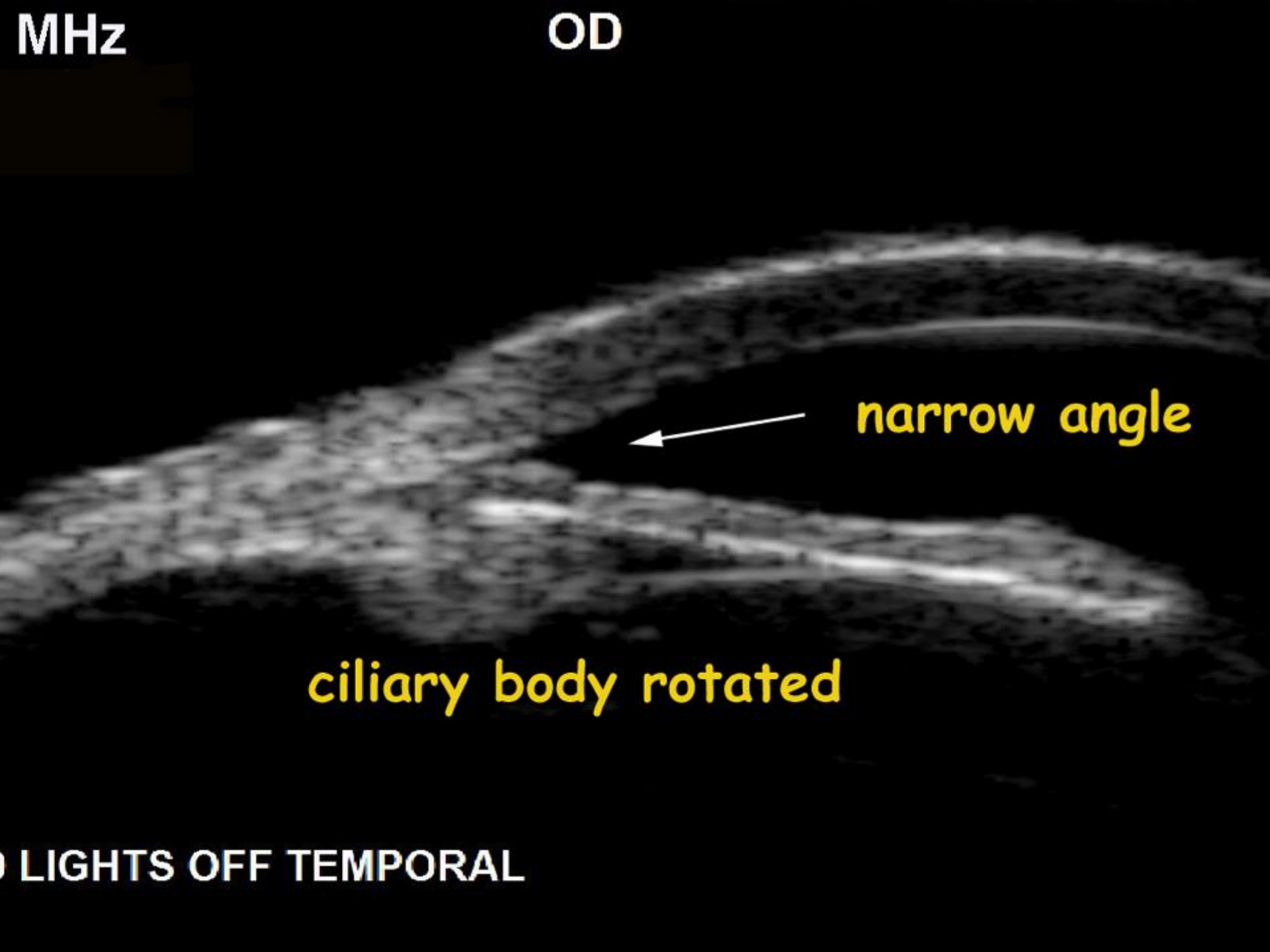
Aqueous Humour

- Formation
  - Secretion / diffusion / ultrafiltration from ciliary body
  - 'Plasma-like'
  - Replaced every 100 minutes
- Drains through
  - Trabecular meshwork
  - Uveoscleral Unconventional pathway
- Function
  - Maintenance of IOP
  - Contributes to transparency
  - Metabolic support for lens, cornea & vitreous

Aqueous Humour Outflow

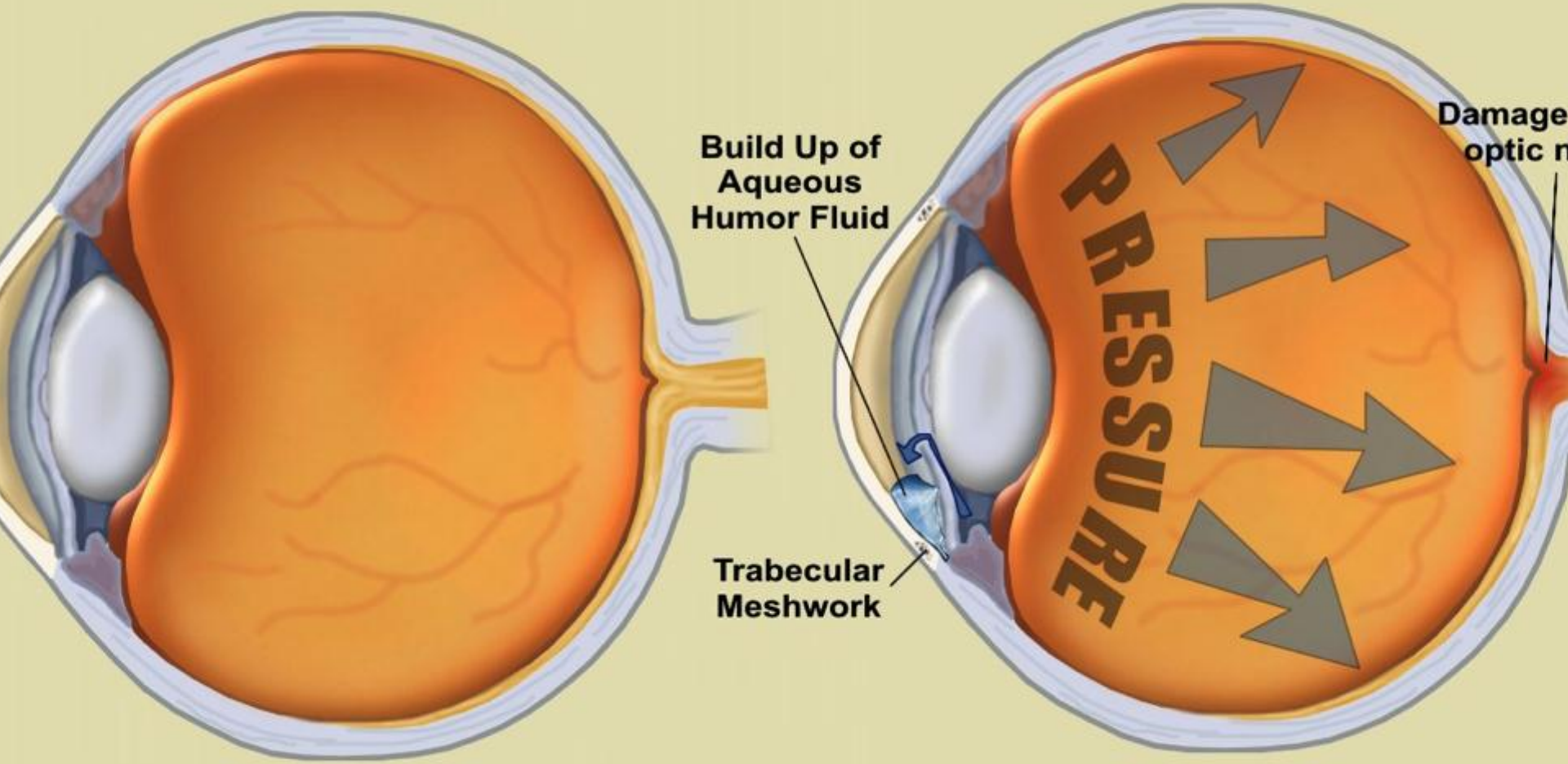



Iris
CLOSED ANGLE
Schlemm's canal
Episcleral vein
Aqueous vein
Trabecular meshwork
Ciliary body
Aqueous flow


MHz
OD
narrow angle
ciliary body rotated
LIGHTS OFF TEMPORAL

Normal Eye

Eye with Glaucom



Part V Light Detection

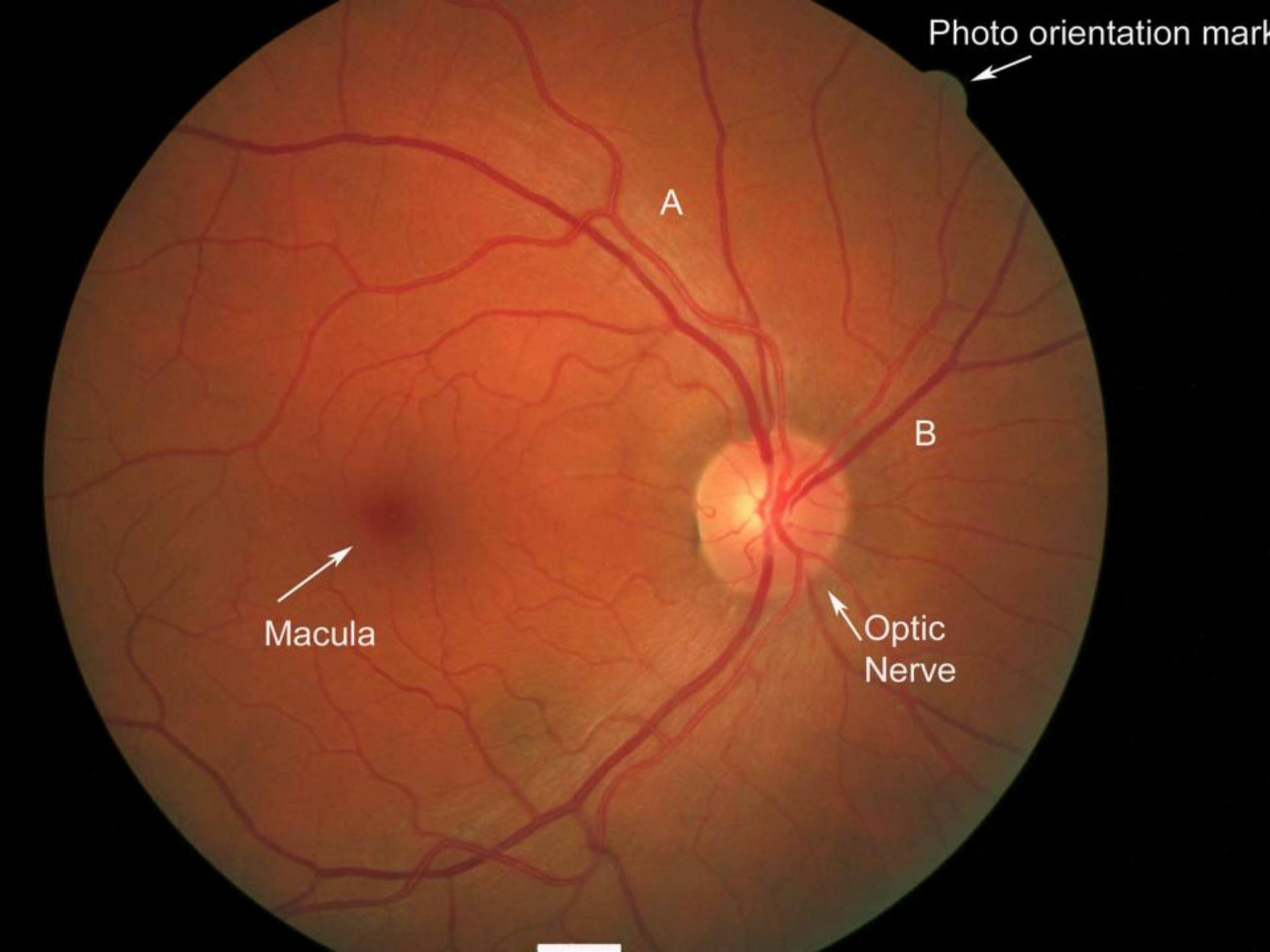
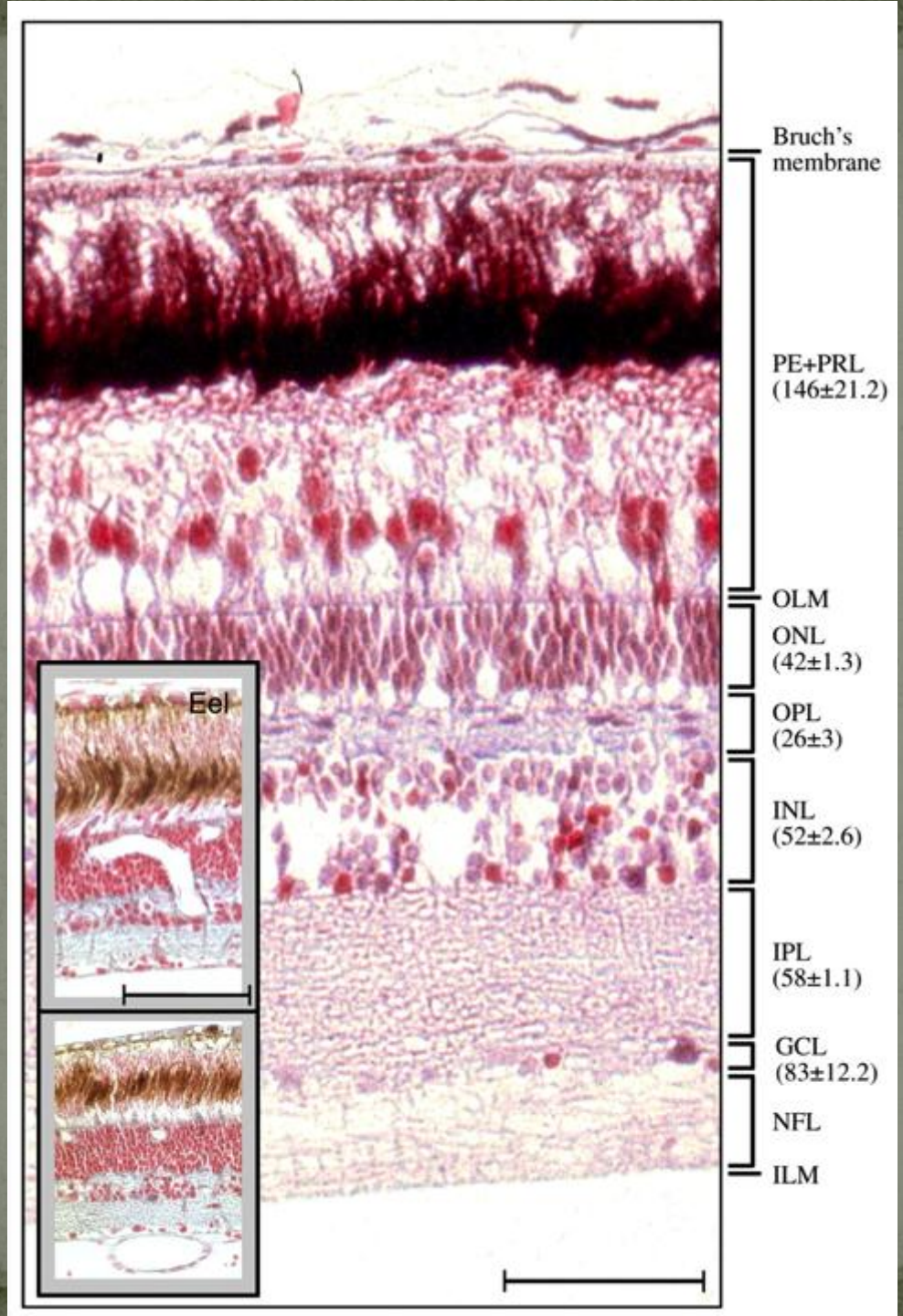
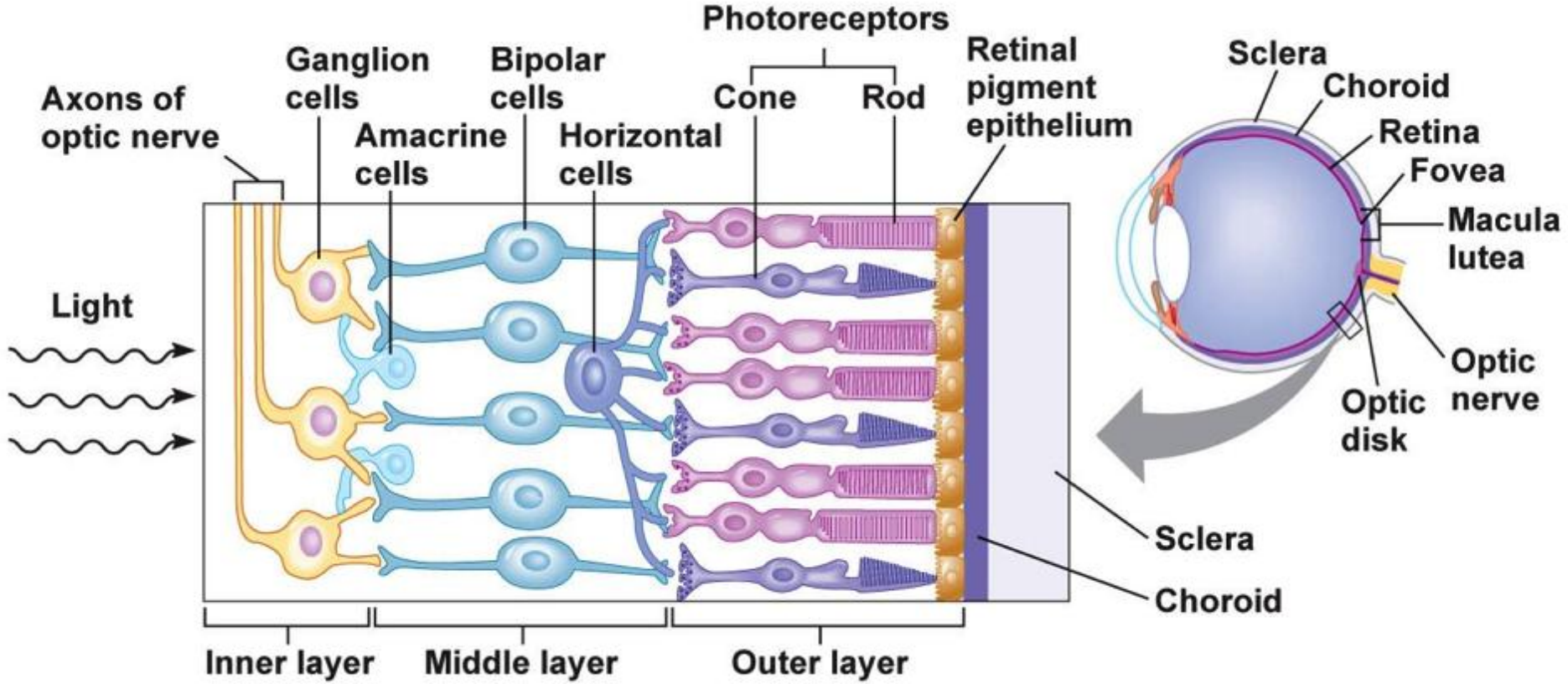
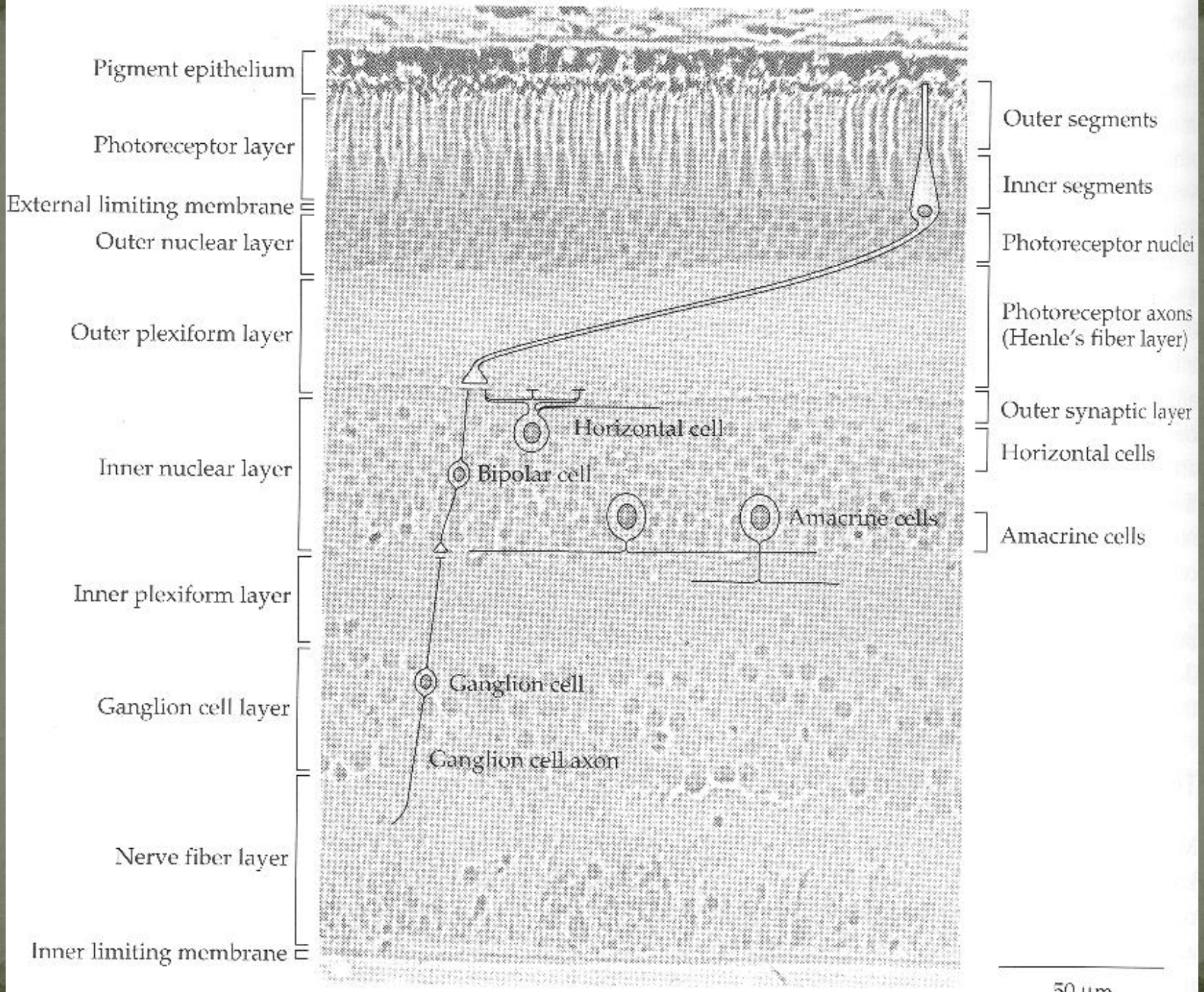


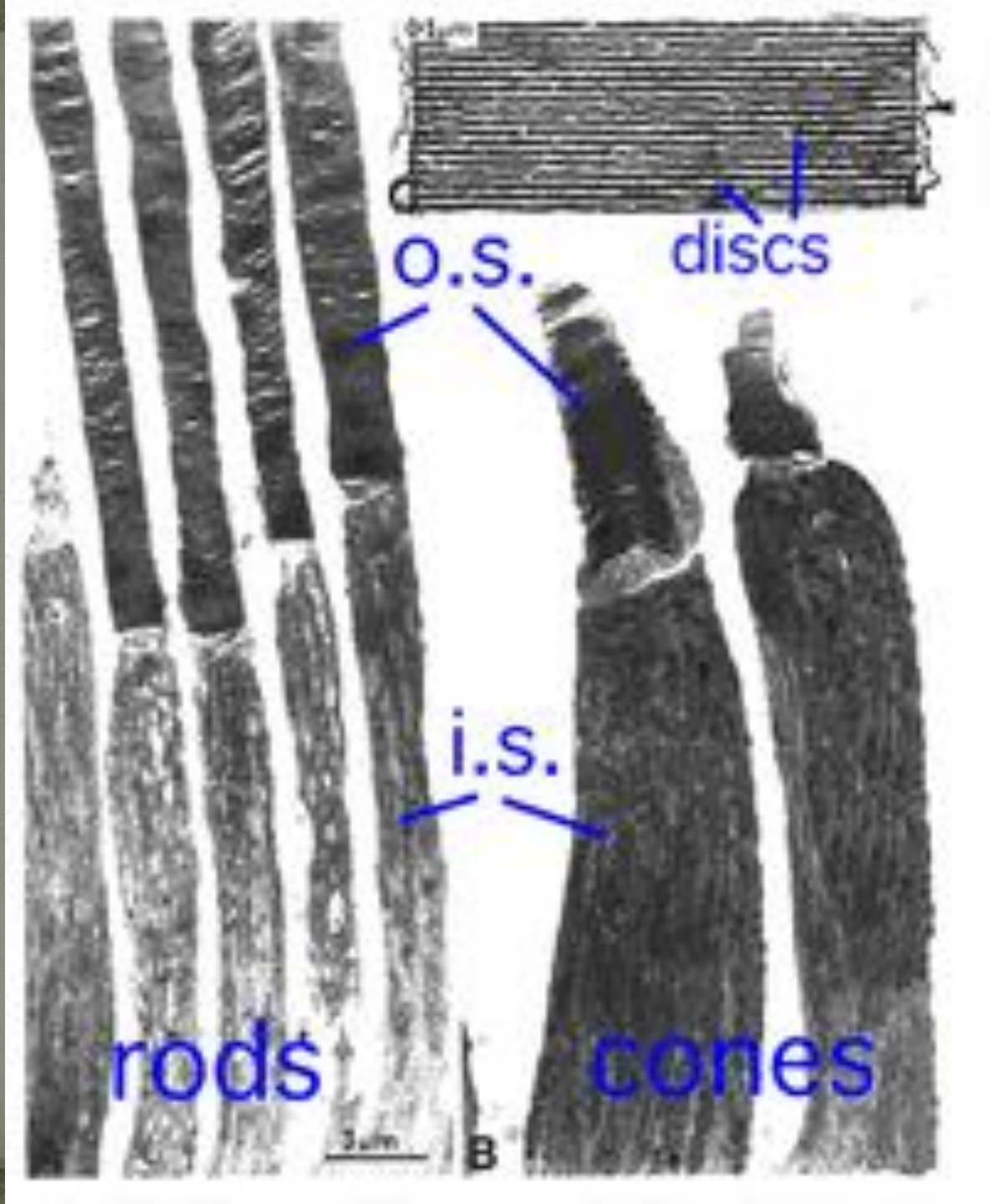
Photo orientation mark
A
B
Macula
Optic
Nerve

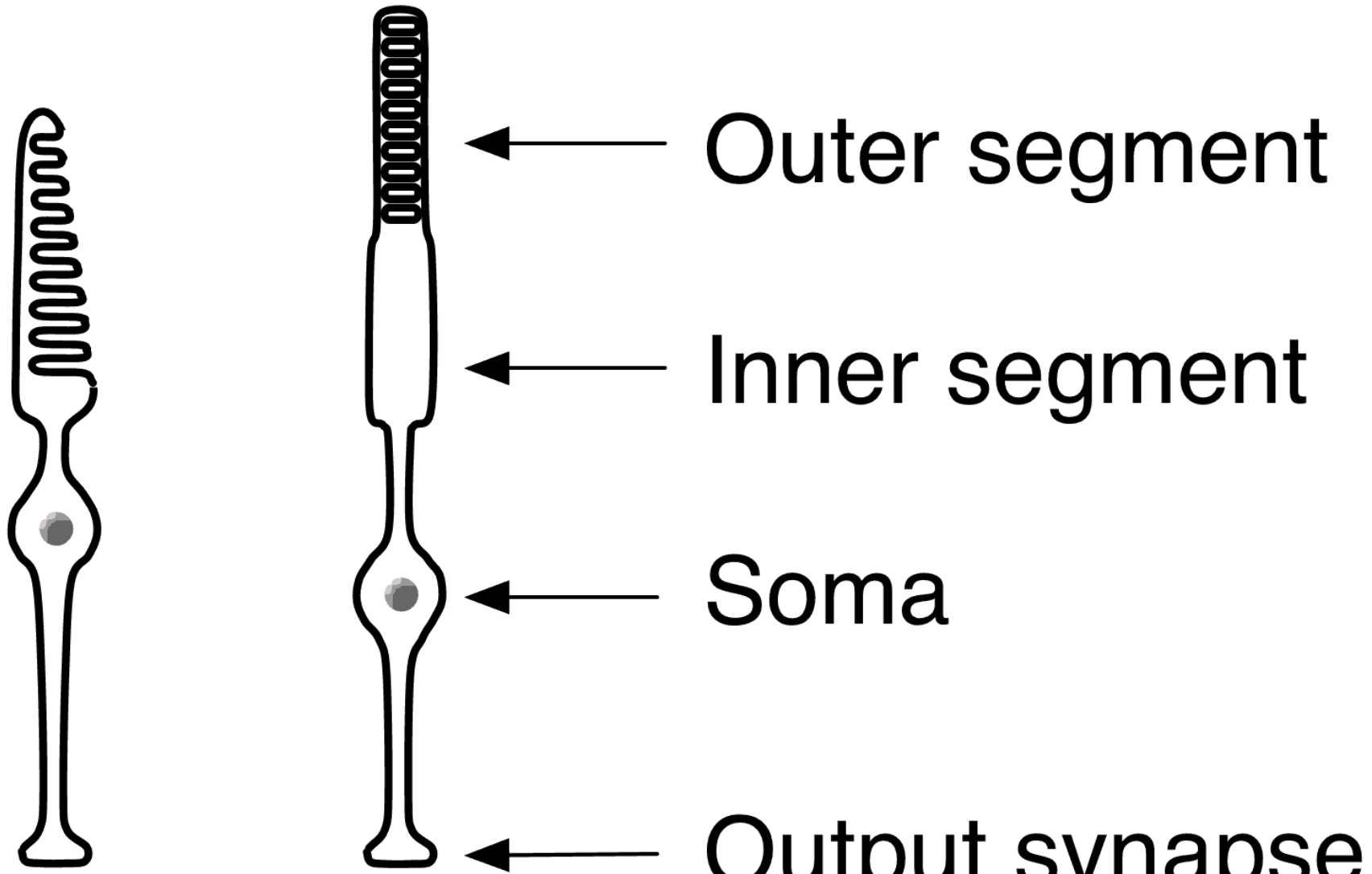

Eel
Bruch's membrane
PE+PRL (146±21.2)
OLM
ONL (42±1.3)
OPL (26±3)
INL (52±2.6)
IPL (58±1.1)
GCL (83±12.2)
NFL
ILM

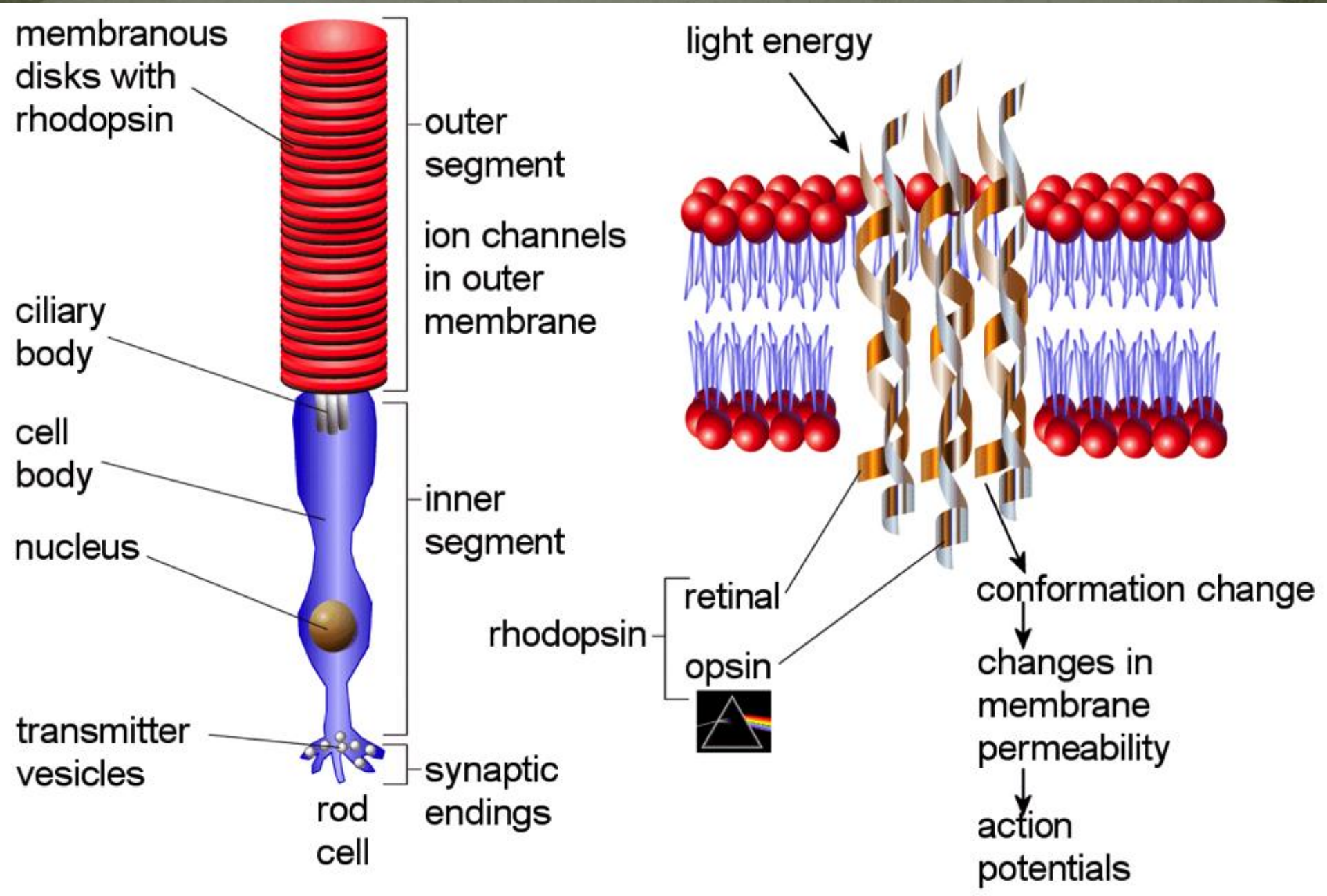
Retina (Schematic Diagram)



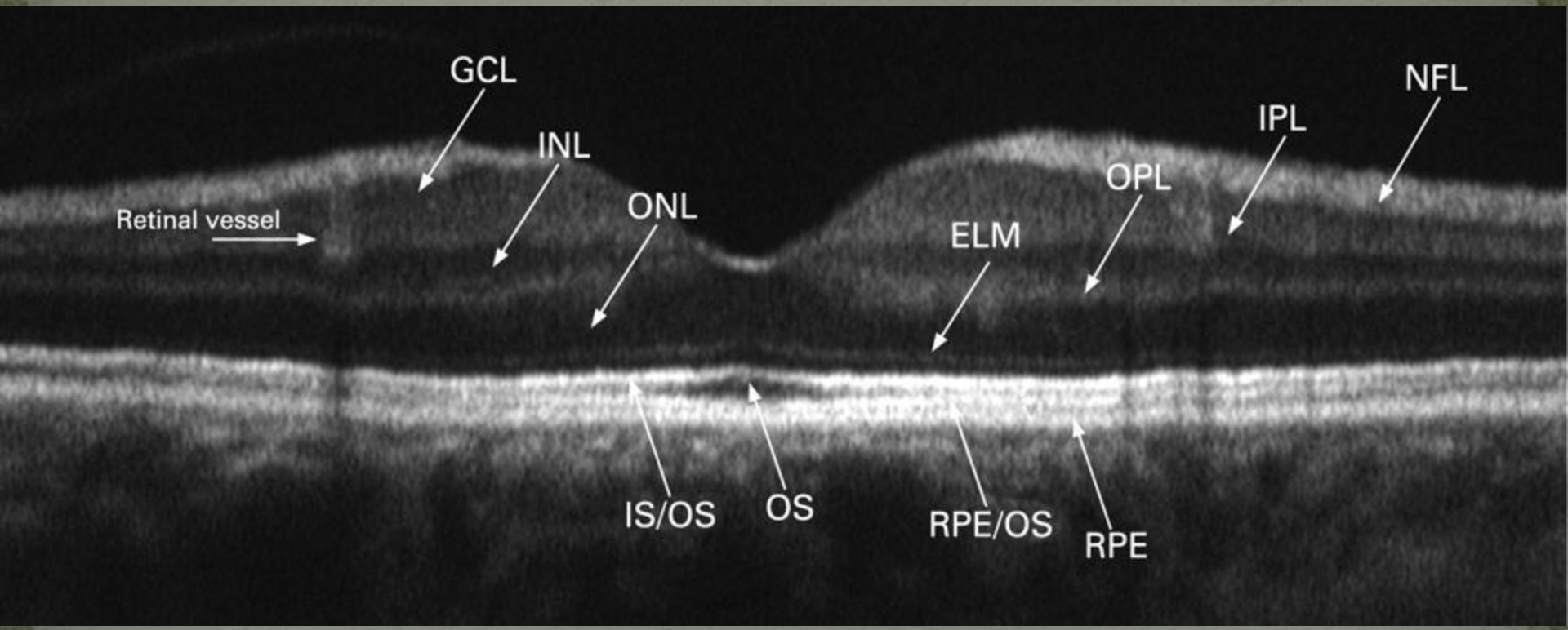

Pigment epithelium
Photoreceptor layer
External limiting membrane
Outer nuclear layer
Outer plexiform layer
Inner nuclear layer
Inner plexiform layer
Ganglion cell layer
Nerve fiber layer
Inner limiting membrane
Outer segments
Inner segments
Photoreceptor nuclei
Photoreceptor axons (Henle's fiber layer)
Outer synaptic layer
Horizontal cells
Amacrine cells
Horizontal cell
Bipolar cell
Amacrine cells
Ganglion cell
Ganglion cell axon
50 μm


discs
o.s.
i.s.
rods
cones
B

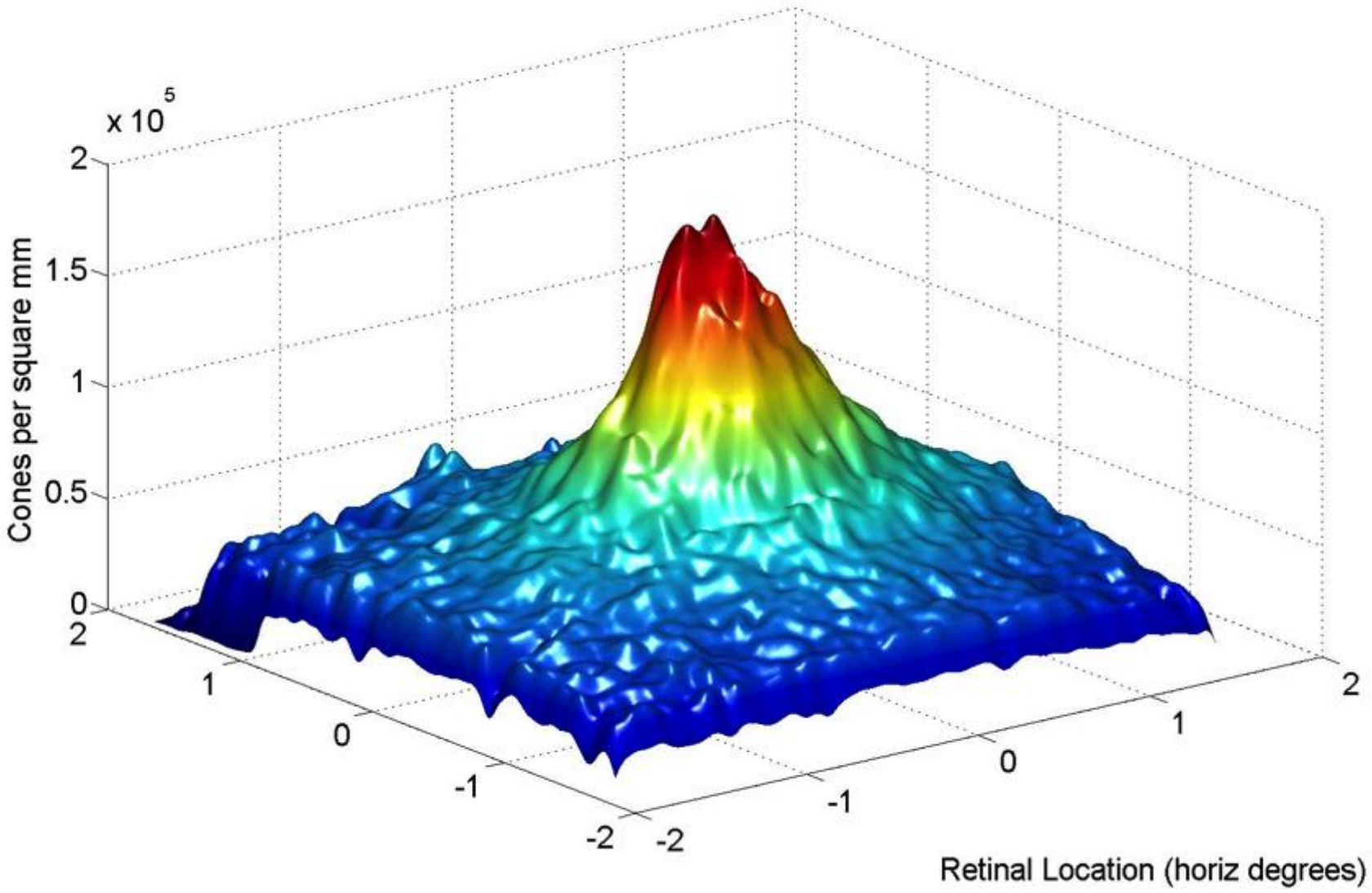

Outer segment
Inner segment
Soma
Output synapse
Cone
Rod

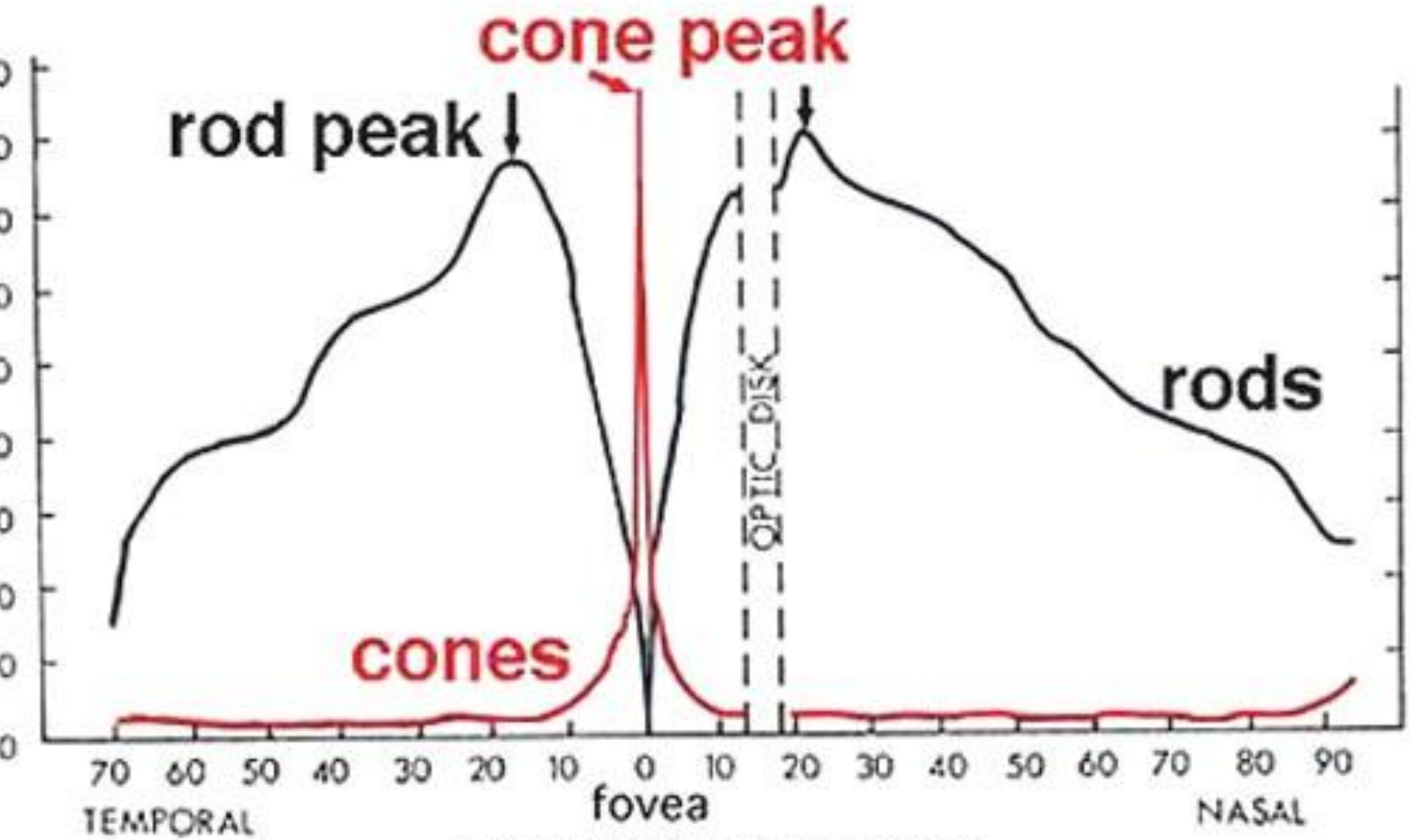

membranous disks with rhodopsin
outer segment
ion channels in outer membrane
ciliary body
cell body
nucleus
inner segment
transmitter vesicles
synaptic endings
rod cell
light energy
rhodopsin
retinal
opsin
conformation change
changes in membrane permeability
action potentials

Macula (Optical Coherence Tomography) Foveal Avascular Zone



Cone Photoreceptor Density



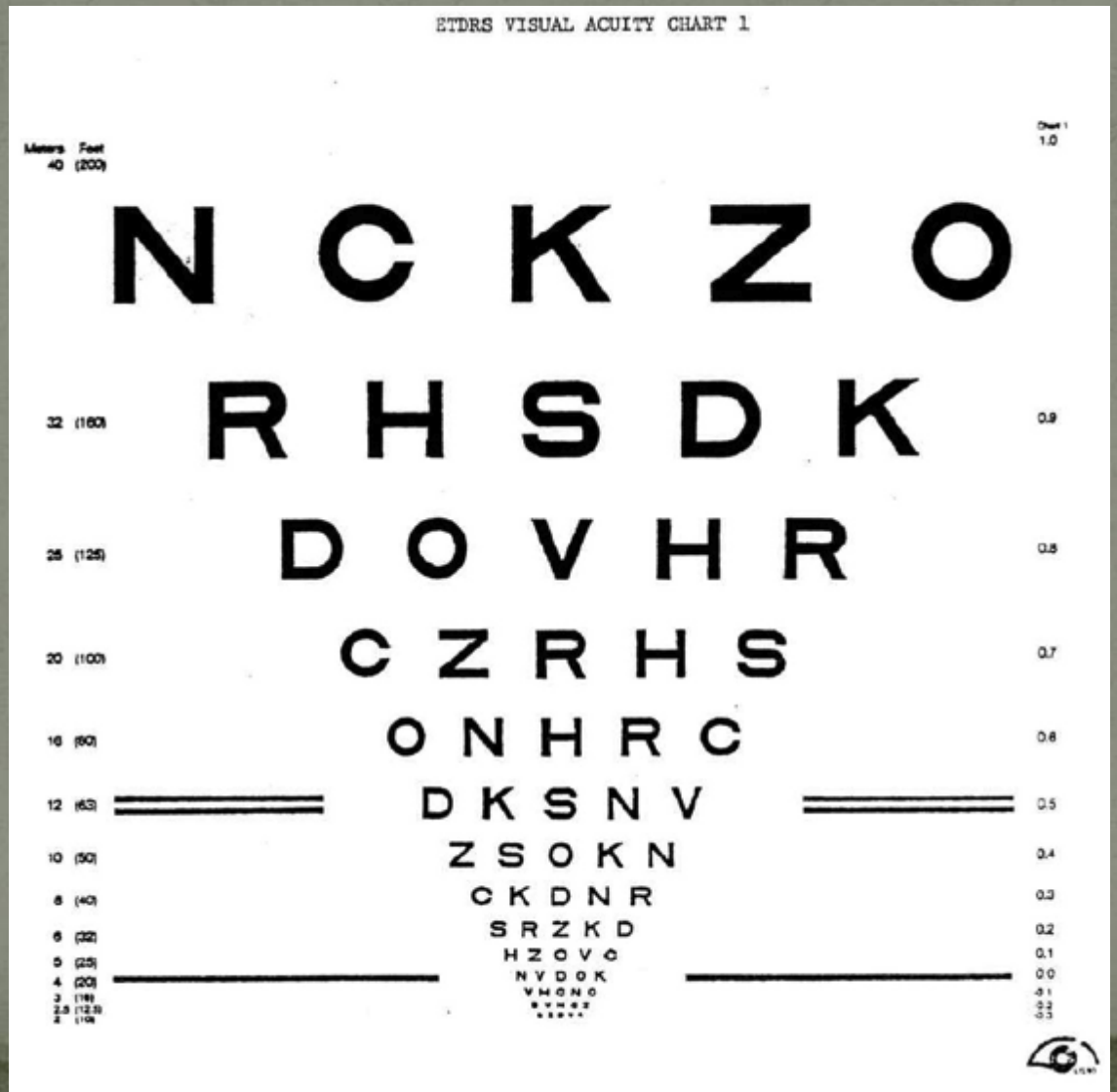


0. Graph to show rod and cone densities along the horizontal meridian

Visual Acuity (Snellen)

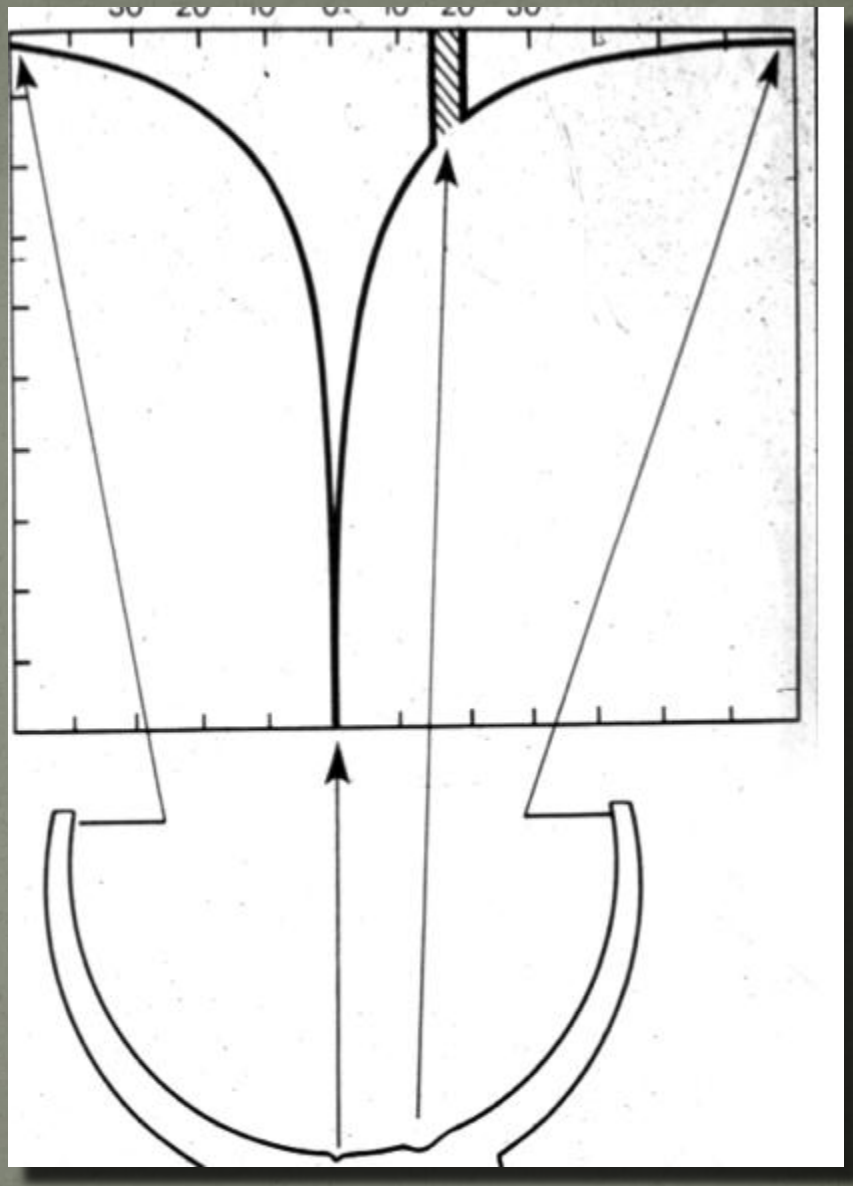
- Measurement of spatial resolving power
- Most commonly measured at 6 metres or 20 feet (in US) using Snellen's chart
- Normal Snellen acuity = 6/6 (or 20/20)
- Predicated on the basis that the normal eye can resolve detail of 1 minute of arc

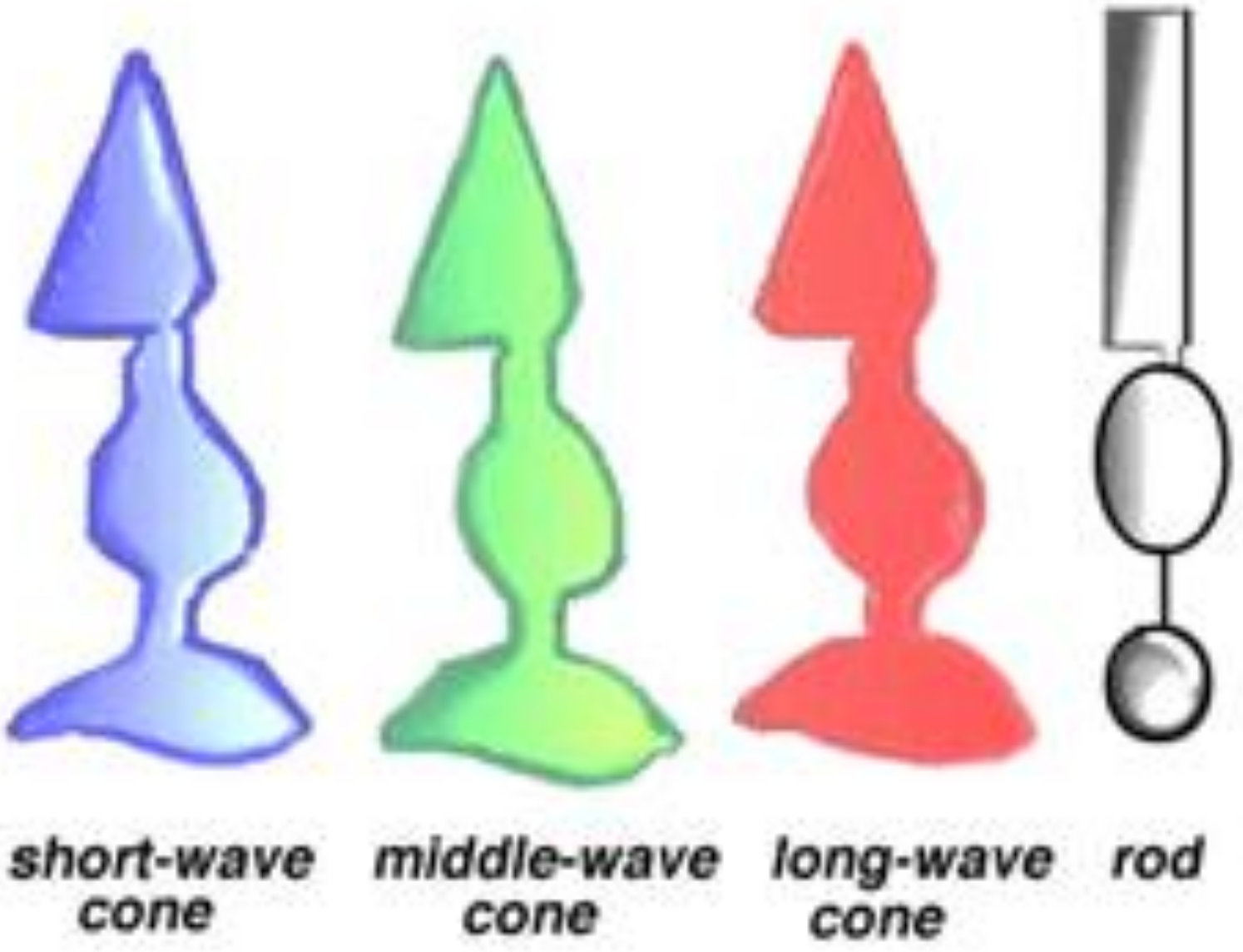
Visual Acuity (EDTRS Chart)

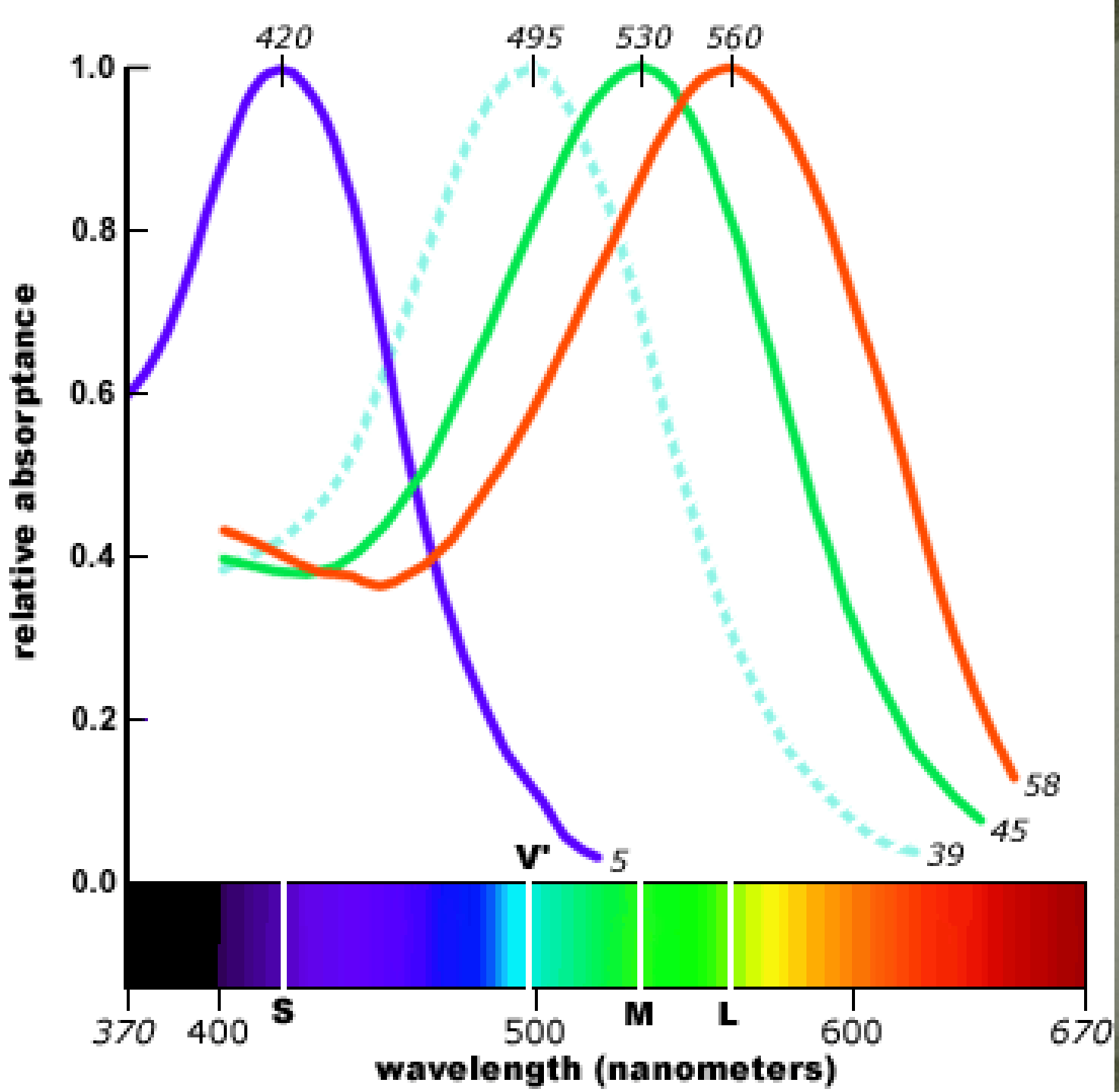


Eccentric Viewing

- N.B. rapidity of fall-off in acuity as move away from fovea - by 1 degree acuity is 60% of foveal maximum



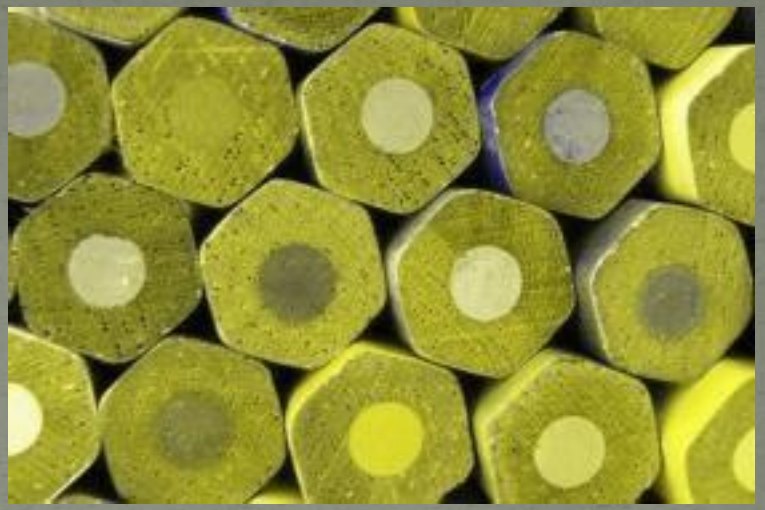
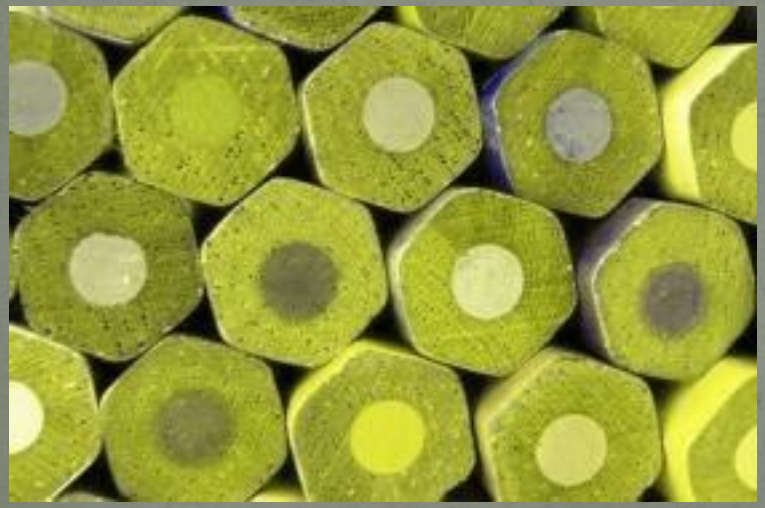

short-wave cone
middle-wave cone
long-wave cone
rod


420
495
530
560
1.0
0.8
0.6
0.4
0.2
0.0
relative absorptance
58
45
39
5
V'
370
400
S
500
M
L
600
670
wavelength (nanometers)

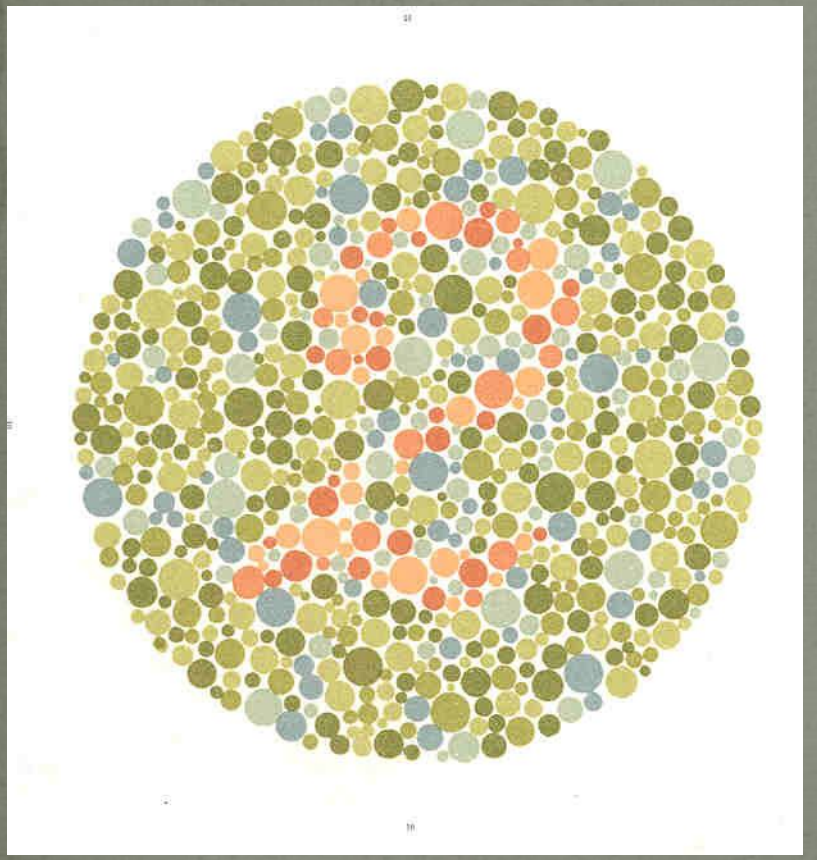
Why do we need colour?

Colour Dificiencies

- Congenital colour deficiencies - affecting 8% males, 0.5% females
- Monochromatism – no cones or blue cones only
- Dichromatism – 2 cone types (dogs)
  - Tritanopia – missing S-cone
  - Deuteranopia – missing M-cone
  - Protanopia – missing L-cone
- Anomalous Trichomatism – shifted peaks
  - Tritanomaly – malfunctioning S-cone
  - Deuteranomaly – malfunctioning M-cone
  - Protanomly –malfunctioning L-cone

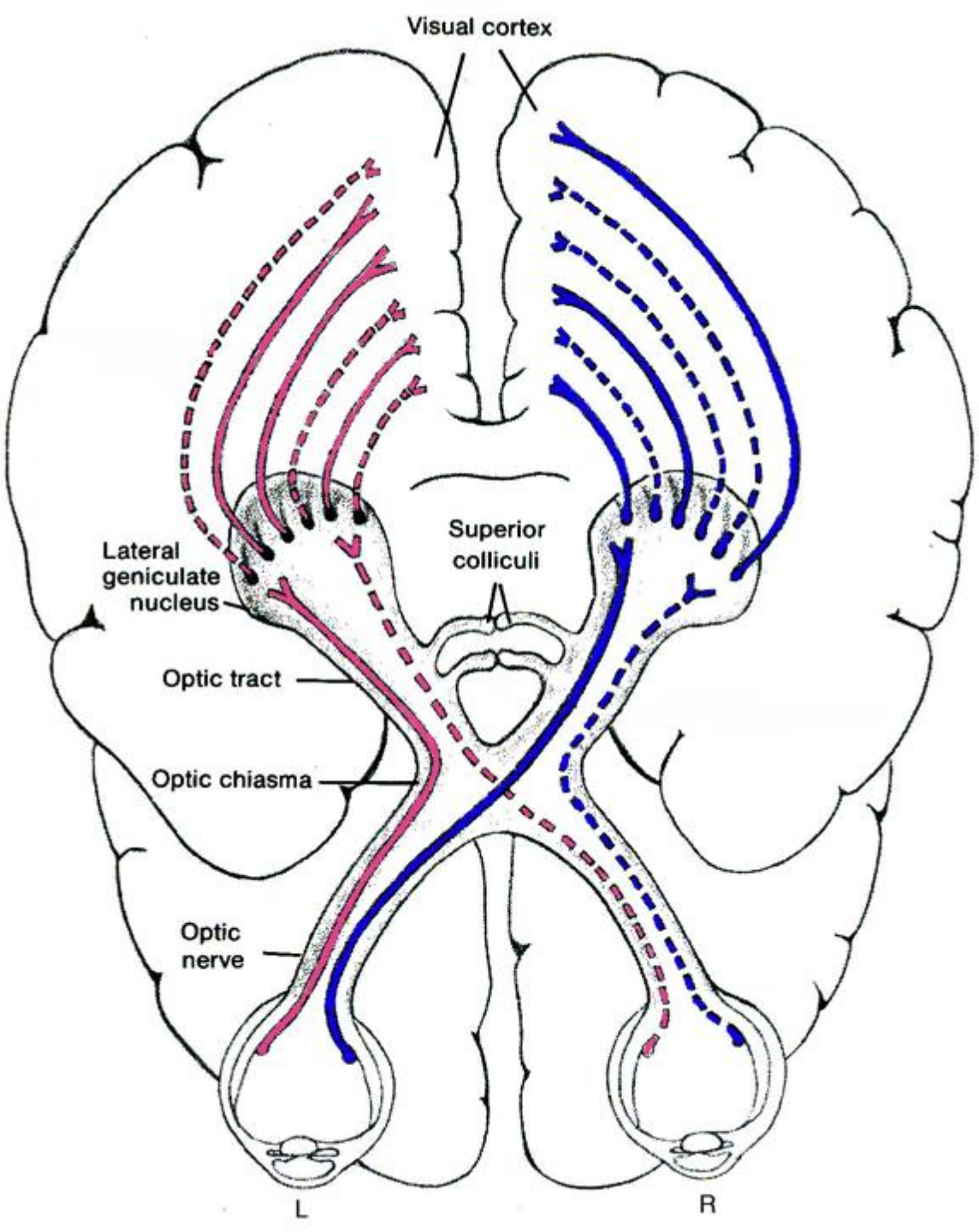

Ishihara Test (Red-Green)



Farnsworth-Munsell Test

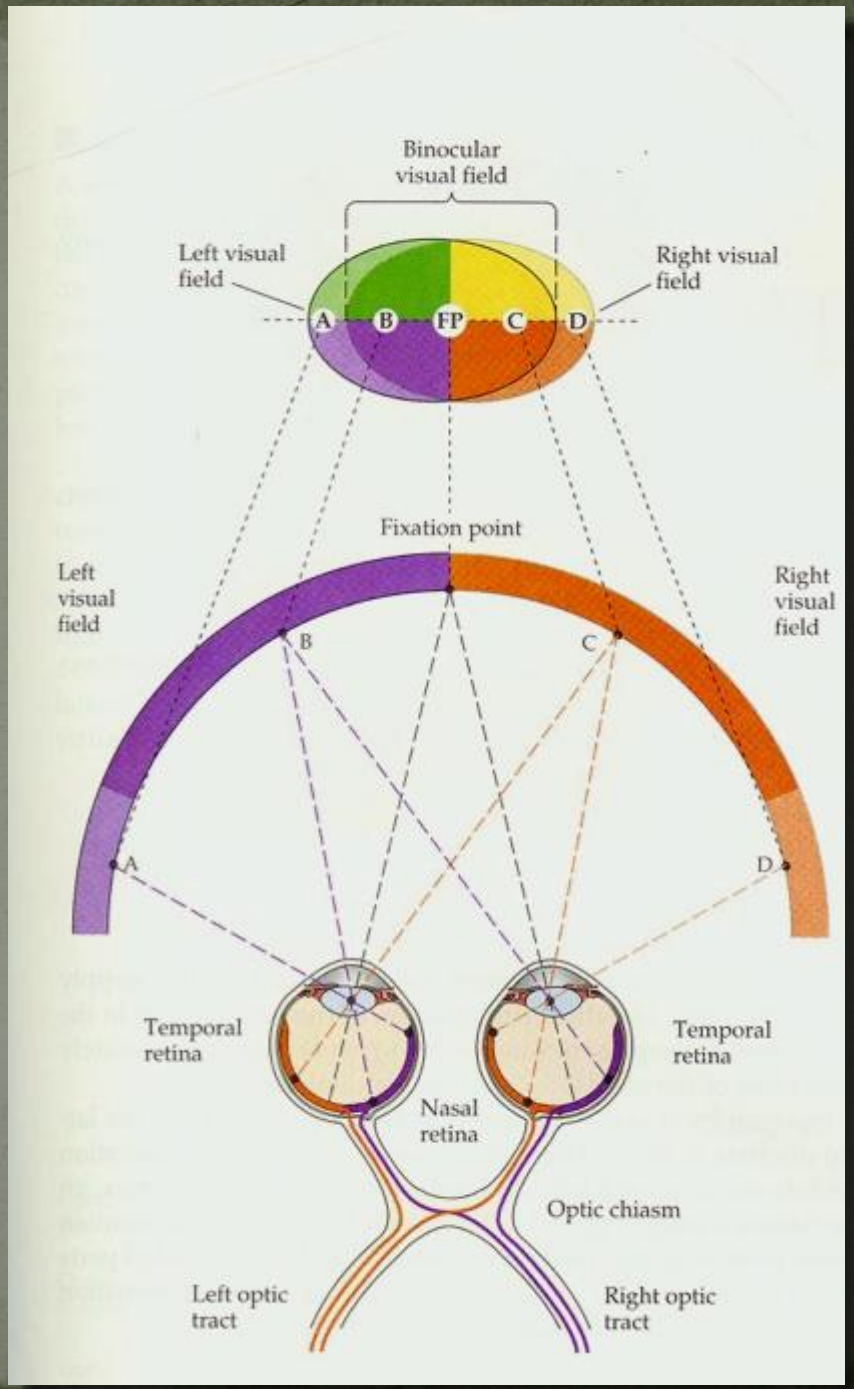
Part VI Vision

Primary Visual Pathway



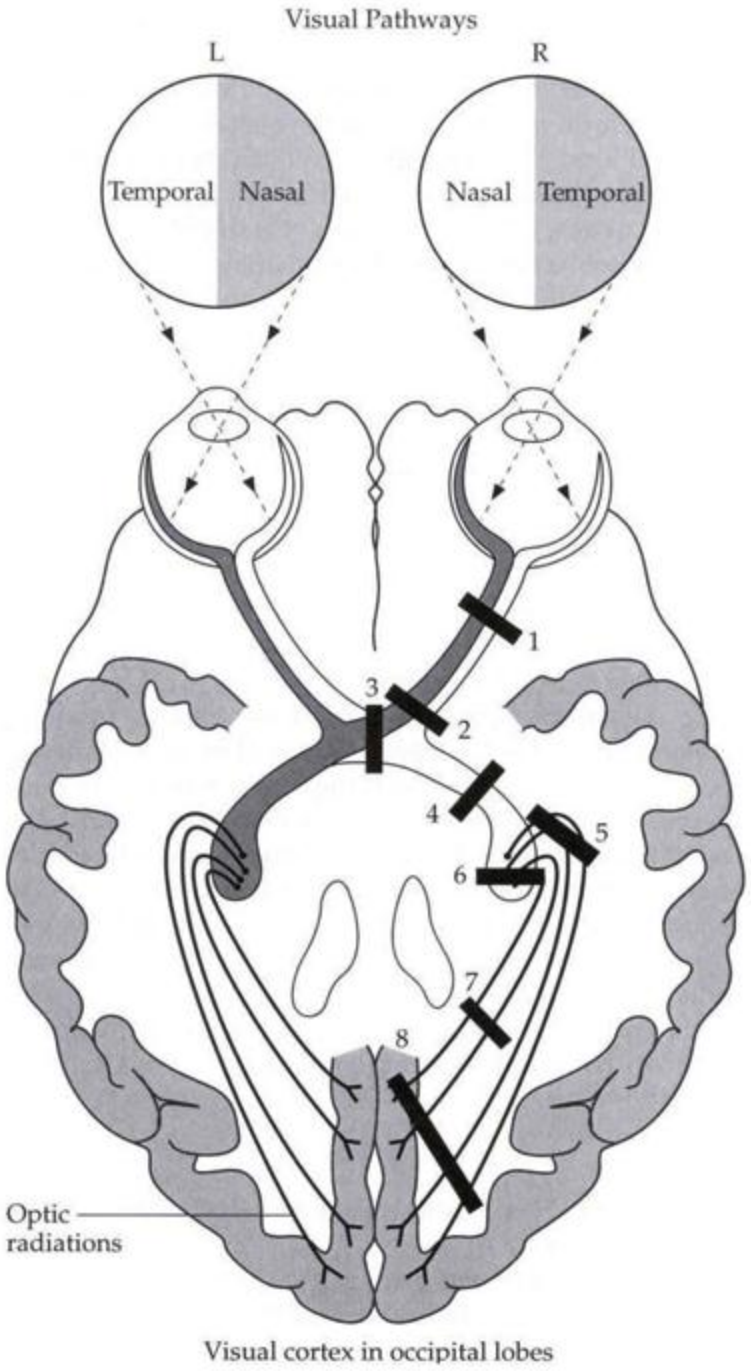
Retinal projections of the visual field

- Left field: maps to nasal retina of left eye and temporal retina of right eye
- Right field: maps to temporal retina of left eye and nasal retina of right eye
- NB temporal fibres do not cross at the chiasm

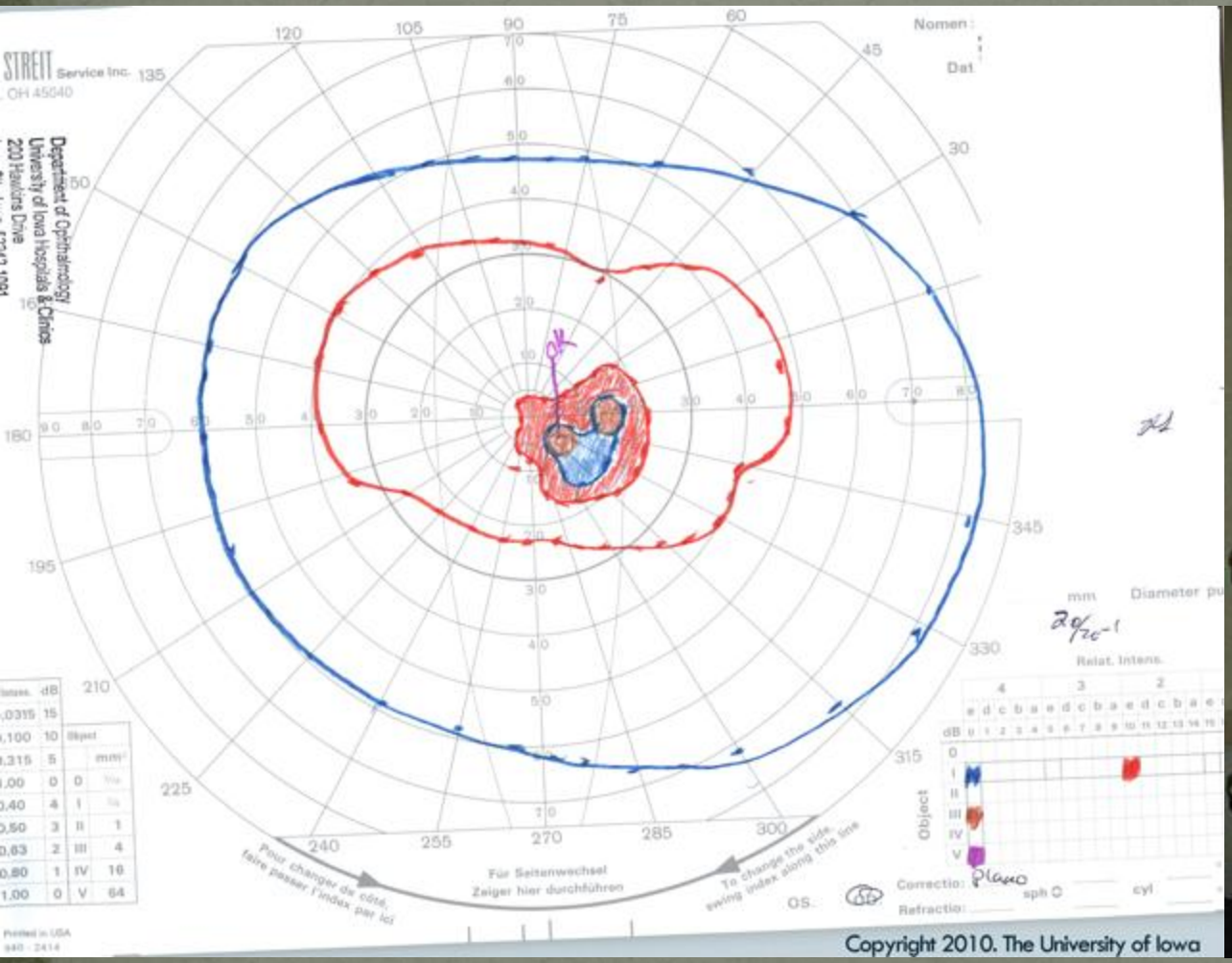


Field Defects

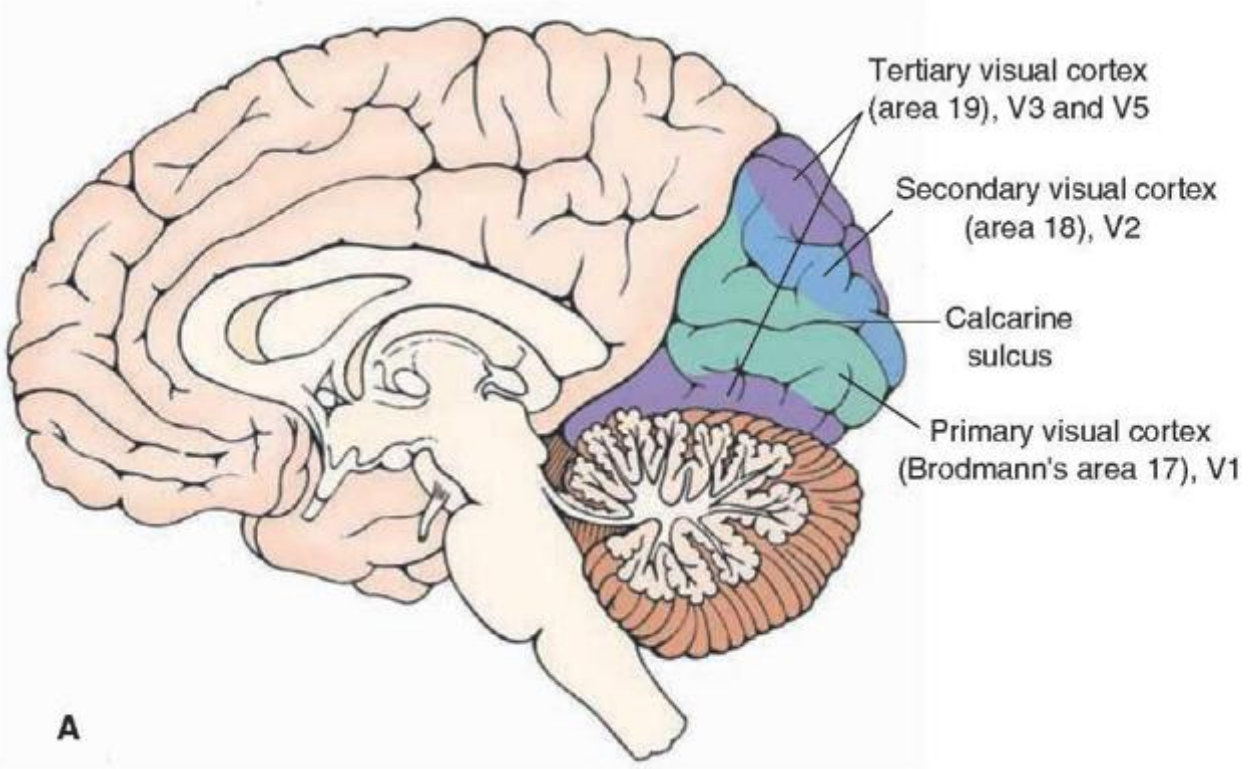
- 1 Unilateral Vision Loss
- 2 Junctional Scotoma
- 3 Bitemporal
- Hemianopia
- 4 Homonymous Hemianopia
- 5 Homonymous Superior Quadranopia
- 6 Homonymous Hemianopia
- 7 Homonymous Inferior Quadranopia
- 8 Homonymous Hemianopia with Macula Sparing

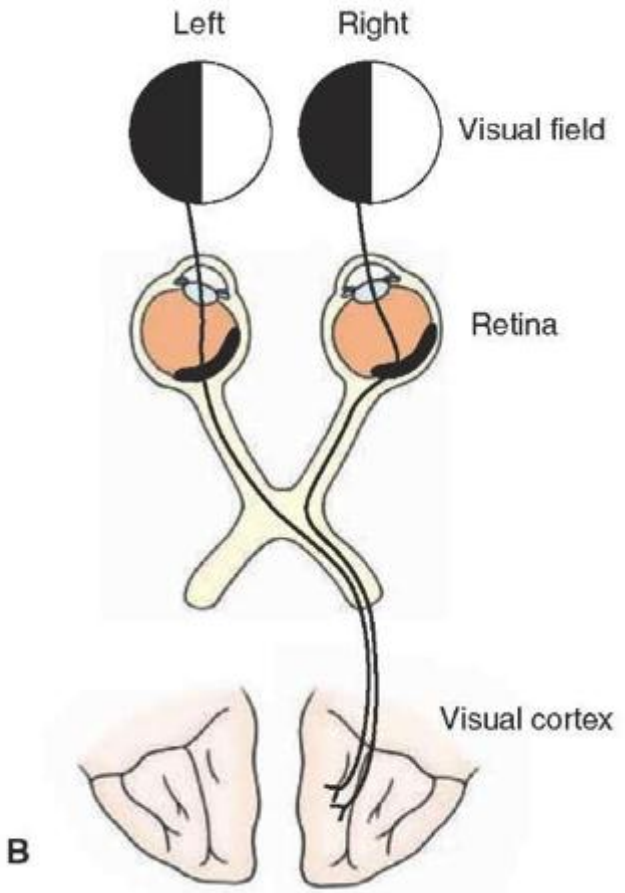


Goldmann Visual Field



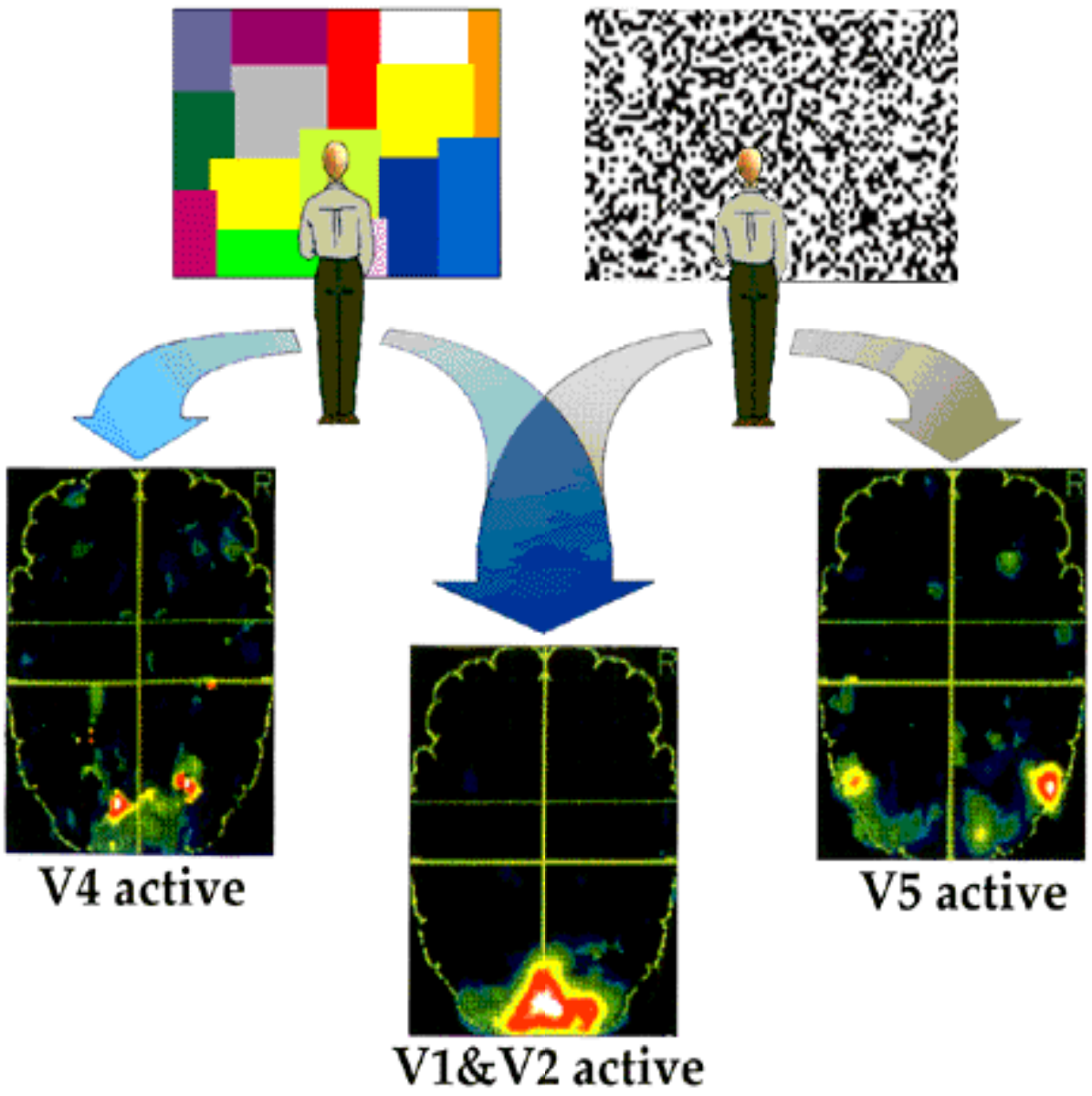
Visual Cortex





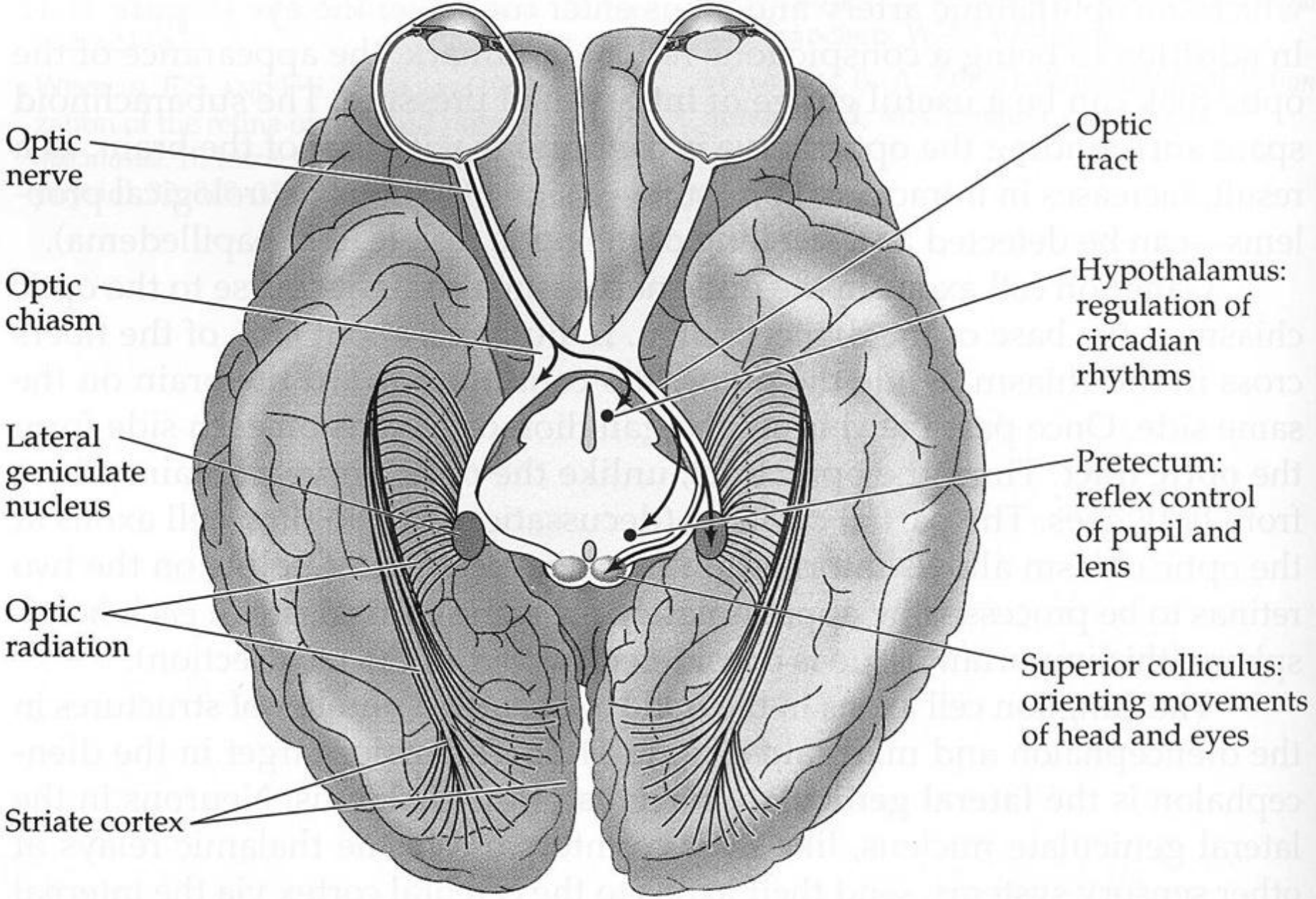
Functional Specialization in Extrastriate Cortex

- Visual processing continues beyond the striate visual cortex (V1) into extrastriate regions (V2, V3, V4, V5/MT, V6, V7, V8)
- Evidence
  - Animal
  - Clinical conditions (e.g. cerebral achromatopsia)
  - Imaging (e.g. PET, fMRI)


V4 active
V1&V2 active
V5 active

Circadian Visual Pathway

- Retinohypothalamic tract (RHT)
- Biological clock in SCN of hypothalmus
- Light-dark cycle major zeitgeber (entrains biological clock)
- Intrinsically photoreceptive ganglion cells (iPRCs) containing melanopsin
- N.B. lesions of RHT - 'circadian blindness'


Optic nerve
Optic chiasm
Lateral geniculate nucleus
Optic radiation
Striate cortex
Optic tract
Hypothalamus: regulation of circadian rhythms
Pretectum: reflex control of pupil and lens
Superior colliculus: orienting movements of head and eyes