Optics of the Human Eye

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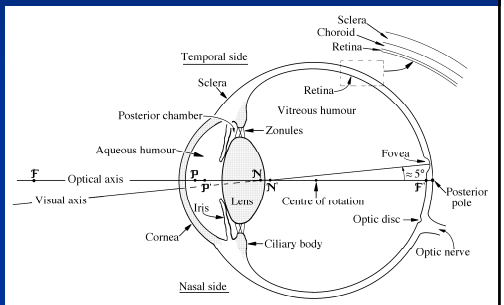
Scope

- Optical Structure
- Optical Structure and Image Formation
- Refractive Components
- Refractive Anomalies
- The Ageing Eye

Optical Structure – cornea and sclera

The outer layer of the eye is in two parts: the anterior cornea and the posterior sclera

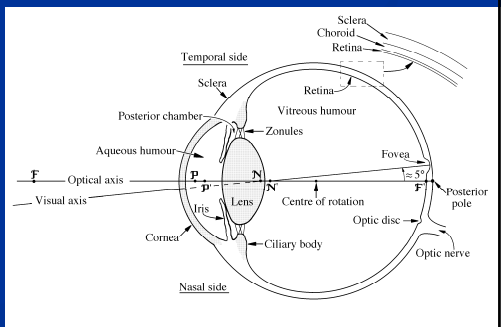
- The cornea is transparent and approximately spherical with an outer radius of curvature of about 8 mm
- The sclera is a dense, white, opaque fibrous tissue which is approximately spherical with a radius of curvature of about 12 mm



Optical Structure – uveal tract

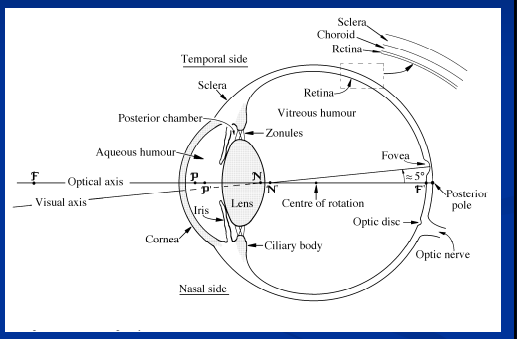
The middle layer of the eye is the uveal tract. It is composed of the iris anteriorly, the choroid posteriorly and the intermediate ciliary body

- The iris plays an important optical function through the size of its aperture
- The ciliary body is important to the process of accommodation (changing focus)



Optical Structure – retina

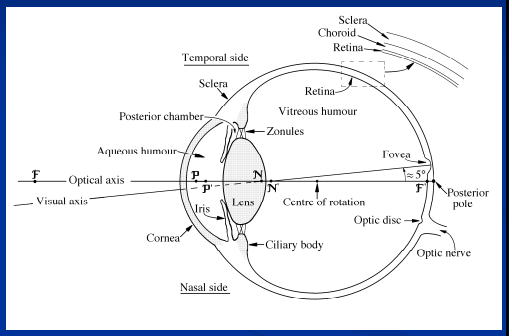
The inner layer of the eye is the retina, which is an extension of the central nervous system and is connected to the brain by the optic nerve



Optical Structure – lens

The lens of the eye is about 3 mm inside the eye

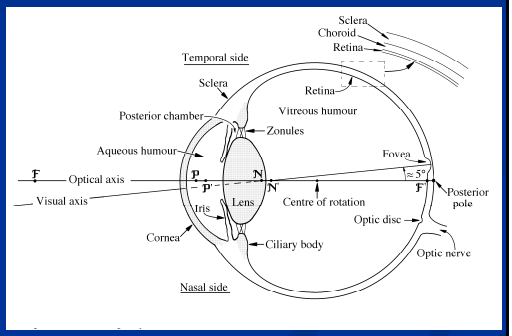
It is connected to the ciliary body by suspensory ligaments called zonules



Optical Structure
- compartments

The inside of the eye is divided into three compartments

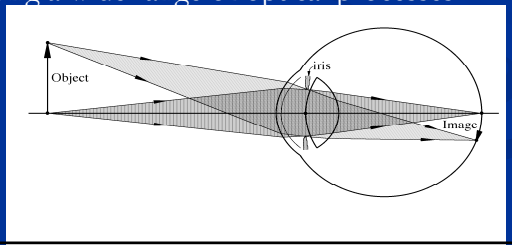
- The anterior chamber between the cornea and iris, which contains aqueous humour
- The posterior chamber between the iris, the ciliary body and the lens, which contains aqueous humour
- The vitreous chamber between the lens and the retina, which contains a transparent gel called the vitreous humour



Optical Structure and Image Formation

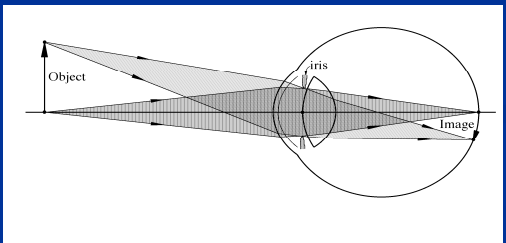
Principles of image formation by the eye are same as for man-made optical systems

- Light enters the eye through the cornea and is refracted by the cornea and lens. The cornea has the greater power.
- The lens shape can be altered to change its power when the eye needs to focus at different distances (accommodation).
- The beam diameter is controlled by the iris, the aperture stop of the system. The iris opening is called the pupil. The aperture stop is a very important component of an optical system, affecting a wide range of optical processes.



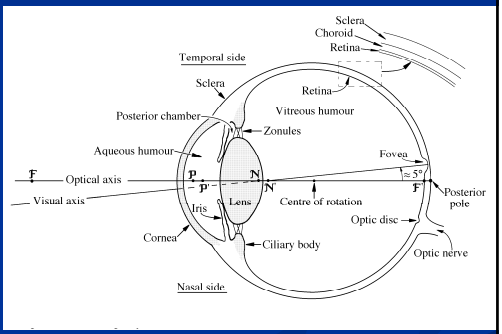
Optical Structure and Image Formation (cont.)

The image on the retina is inverted - like a camera



Optical Structure and Image Formation - optic disc and blind spot

- The optic nerve leaves the eye at the optic disc. This region is blind.
- The optic disc is about 5º wide and 7º high and is about 15º nasal to the fovea
- The name to the corresponding region in the visual field is the blind spot



Optical Structure and Image Formation - power of the eye

One of the most important properties of any optical system is its equivalent power

- Measure of the ability of the system to bend or deviate rays of light
- The higher the power, the greater is the ability to deviate rays
- Equivalent power F of the eye is given by

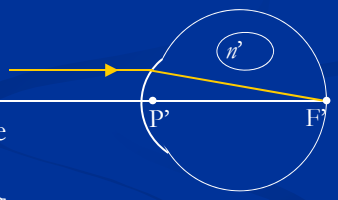
  $F = n'/P'F'$

  P' is the second principal point, just inside the eye

  F' is the second focal point. Light entering the eye from the distance is imaged at F'

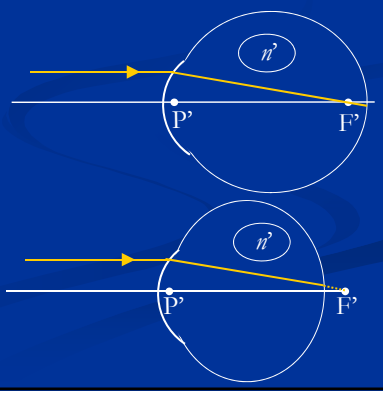
  n' is the refractive index of the vitreous

  The average power of the eye is 60 m^{-1} or 60 dioptres (D)



Optical Structure and Image Formation - refractive error

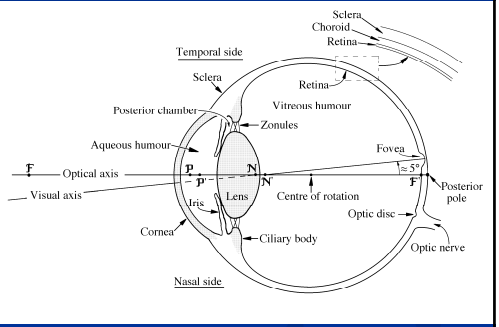
- Refractive error more important than the equivalent power
- Can be regarded as an error in the length due to a mismatch with the equivalent power
- If the length is too great for its power, the image is formed in front of the retina and this results in *myopia*
- If the length is too small, the image is formed behind the retina and this results in *hypermetropia*



Optical Structure and Image Formation - axes

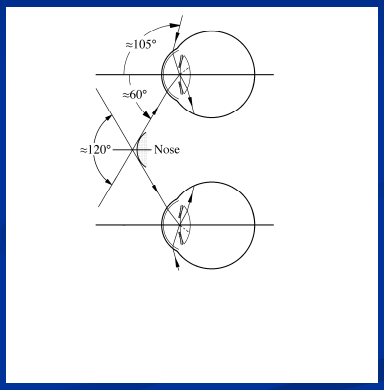
The eye has a number of axes. Two important ones are the optical axis and the visual axis

- Optical axis: Surfaces centres of curvatures are not co-linear, there is no true optical axis – taken as the line of best fit through these points
- Visual axis is one of the lines joining the object of interest and the centre of the fovea



Optical Structure and Image Formation - field of vision

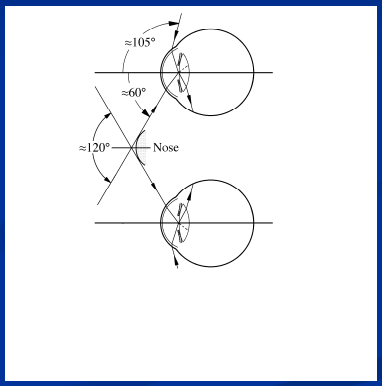
- Temporal field: about 105°
- Nasal field: only about 60° because of the combination of the nose and the limited extent of the temporal retina
- Superiorly and inferiorly: about 90°, except for anatomical limitations



Optical Structure and Image Formation - binocular vision

The use of two eyes provides better perception of the external world than one eye alone

- Two eyes laterally displaced by ~60 mm give the potential for a 3-D view of the world, including the perception of depth known as stereopsis
- The total field of vision in the horizontal plane is about 210°
- Binocular overlap is 120°



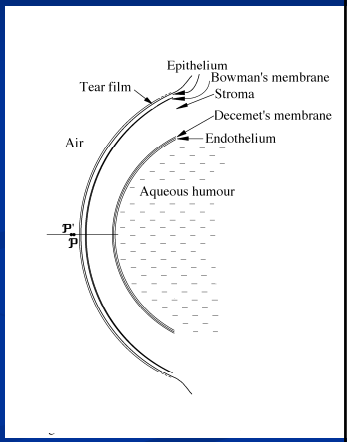
Refracting Components

Refracting components are cornea and lens

- Elements must be transparent and have appropriate curvatures and refractive indices
- Refraction takes place at four surfaces - the anterior and posterior surfaces of the cornea and lens
- There is also continuous refraction within the lens

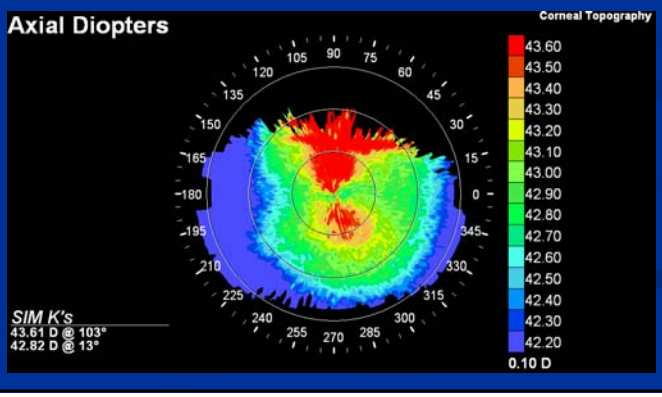
Refracting Components - cornea

- 40 D (2/3rds power) provided by the cornea
- Supports the tear film and has a number of layers
- ~ 0.5 mm thick in centre
- Posterior surface is more curved than the anterior surface
- The anterior surface has greater power (48 D) than the posterior surface (-8 D) because of low refractive index difference between the cornea and aqueous



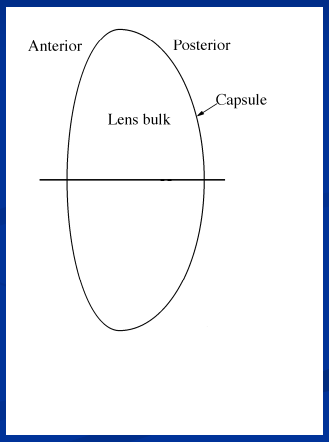
Refracting Components – cornea (cont.)

- Frequently curvature is different in different meridians (toric)
- In general, the radius of curvature increases with distance from the surface apex - aspheric
- Corneal surface asphericity influences higher order aberrations (subtle optical defects)



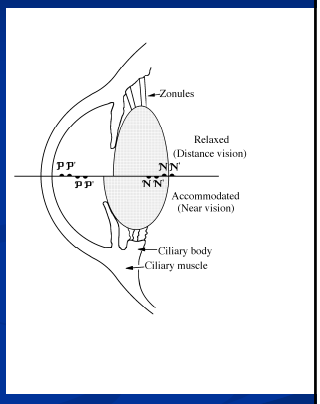
Refracting Components - lens

- Lens bulk is a mass of cellular tissue of non-uniform refractive index, contained within an elastic capsule
- Do not yet have an accurate measure of refractive index distribution
- Most cells are long fibres which have lost their nuclei
- Lens grows continuously with age, with new fibres laid over the older fibres
- Anterior radius of curvature is about 12 mm
- The posterior radius of curvature is about -6mm (note negative sign)
- Changes in shape with accommodation and aging, particularly at the front surface



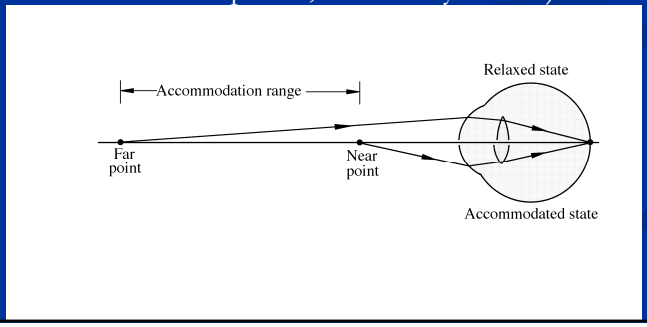
Refracting Components – lens (cont.)

- In accommodation, when the eye changes focus from distant to closer objects:
  - ciliary muscle contracts and causes the zonules supporting the lens to relax
  - This allows the lens to become more rounded under the influence of its elastic capsule, thickening at the centre and increasing the surface curvatures, particularly the anterior surface
  - The anterior chamber depth decreases
- In accommodation, when the eye changes focus from close to distance objects:
  - reverse process occurs



Refracting Components – lens (cont.)

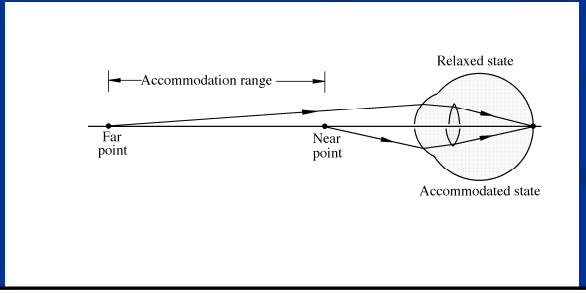
- In a young eye (20 years), accommodation can increase the power of the lens from about 20 to 33 D
- The furthest and closest points that we can see clearly are the far and near points
- The difference between the inverses of their distances from the eye is *amplitude* of accommodation (not quite the same as the increase in lens power, but closely related)



Refractive Anomalies

Ideally, when the eyes fixates an object of interest, the image is sharply focused on the fovea

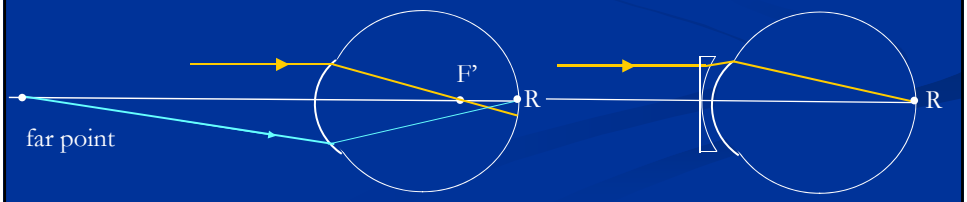
- An eye with a far point of distinct vision at infinity is called an *emmetropic* eye. This is regarded as the "normal" eye, provided that it has an appropriate range of accommodation
- A refractive anomaly occurs if the far point is not at infinity. An eyes whose far point is not an infinity is referred to as an *ametropic* eye.



Refractive Anomalies - myopia

Common type of anomaly

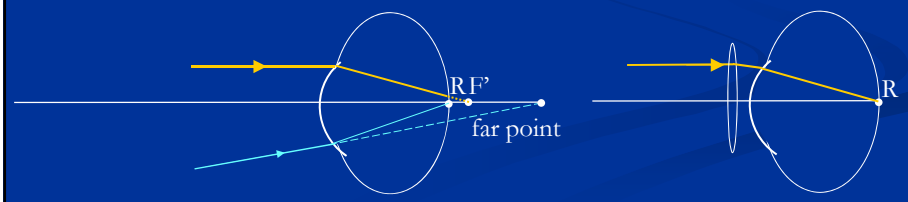
- Far point is at a finite distance in front of the eye
- The back focal point of the eye is in front of the retina
- This eye can focus clearly on distant objects by viewing through a negative powered lens of appropriate power



Refractive Anomalies - hypermetropia

Another common anomaly

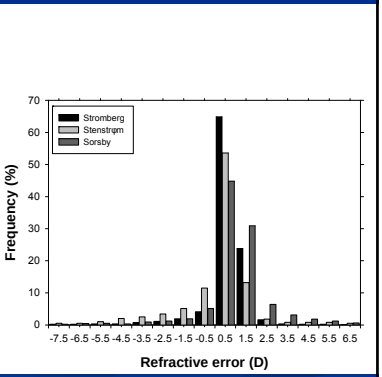
- The far point of the eye lies behind the eye
- Back focal point is behind the retina
- The eye can focus clearly on distant objects
  - If sufficient amplitude of accommodation
  - by viewing through a positive powered lens of appropriate power



Refractive Anomalies – myopia and hypermetropia

Distribution of myopia and hypermetropia in different studies

- These are represented by the powers of the lenses that correct them, with myopia having negative numbers and hypermetropia having positive numbers
- For adult populations, the mean refraction is slightly hypermetropic and the distributions are steeper than normal distributions
- The distributions are skewed - bigger tails in the myopic direction than in the hypermetropic direction



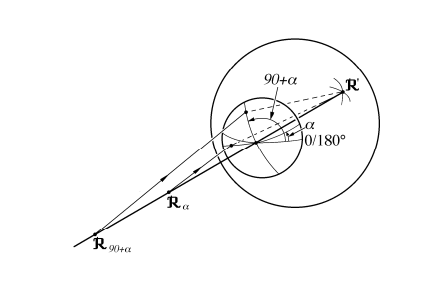
Refractive Anomalies - presbyopia

The range of accommodation is reduced so that near objects of interest cannot be seen clearly

Refractive Anomalies - astigmatism

The power of the eye changes with meridian

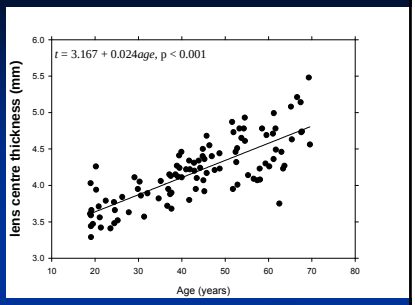
- Usually due to one or more refracting surfaces having a toroidal shape. May be due to surface displacement or tilting. We usually relate this to the error in the principal meridians of maximum and minimum power.
- Astigmatism may be related to myopia and hypermetropia. Hence we may have myopic astigmatism, hypermetropic astigmatism, and mixed astigmatism.

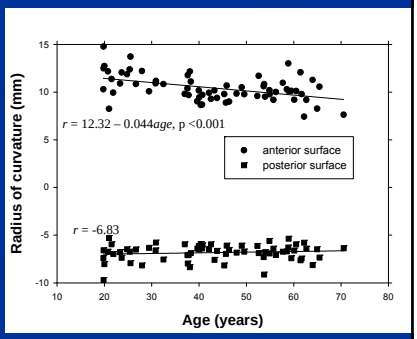


Ageing Eye

Many of the optical changes taking place in the adult eye produce progressive reduction in visual performance. Some of these can be considered as pathological

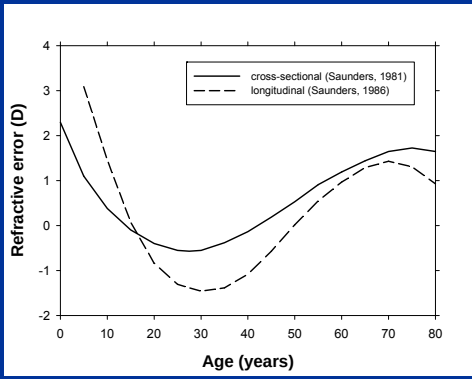
- The most dramatic age-related changes take place in the lens. Its shape, size and mass alter markedly, its ability to vary its shape diminishes and its light transmission reduces considerably. In unaccommodated state:
  - centre thickness ↑ at 0.024 mm/year
  - Anterior surface radius of curvature ↓ at 0.044 mm/year





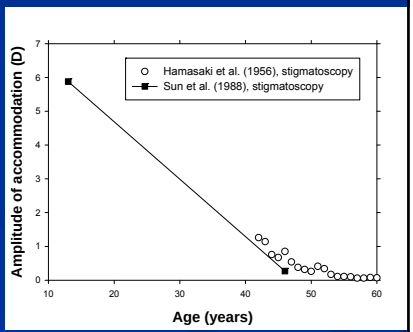
Ageing Eye
– refractive errors

Refractive errors are relatively stable between the ages of 20 and 40 years, after which there is a shift in the hypermetropic direction



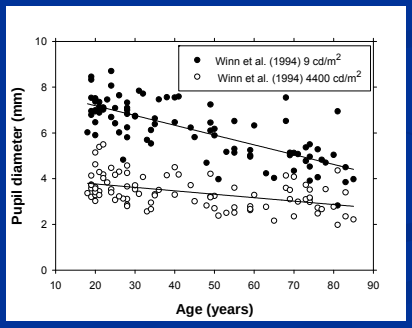
Ageing Eye
- presbyopia

- The amplitude of accommodation reaches a peak early in life, then gradually declines
- Becomes a problem for most people in their forties when they can no longer see clearly to perform near tasks - *presbyopia*
- Accommodation is completely lost in the fifties
- The cause of presbyopia has been controversial in recent years, but the majority of investigators believe that it is due to changes within the lens and capsule in which the lens loses its ability to change shape



Ageing Eye
- pupil diameter

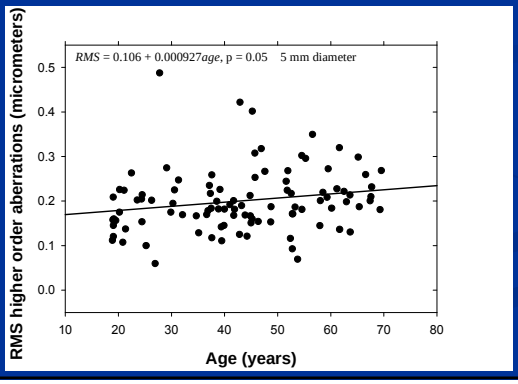
- Pupil diameter – pupil size decreases with increased age. This is referred to as senile miosis
- Light adapted and dark adapted eyes



Ageing Eye
- higher order aberrations

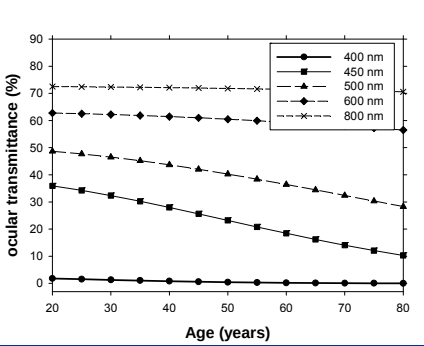
Recent work (pioneered by Pablo Artal) indicates that the subtler optical deffects of the eye increase with age for fixed pupil size

- The reduction in pupil size with eye acts as an influence to moderate these



Ageing Eye
- transmission

- Retinal illumination decreases with age due to light losses within the eye, mainly in the lens (van de Kraats & van Norren, 2007)
- Age related loss greater at short than at long wavelengths

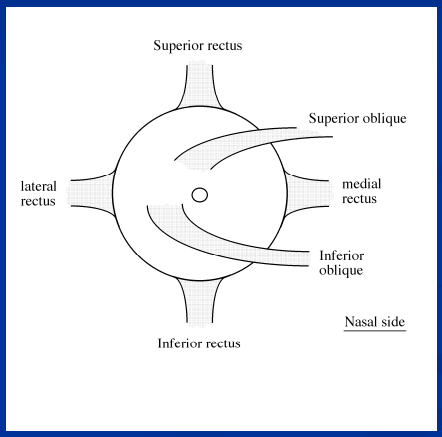


Conclusion

- Optical Structure
- Optical Structure and Image Formation
- Refractive Components
- Refractive Anomalies
- Ageing Eye

Optical Structure (cont.)

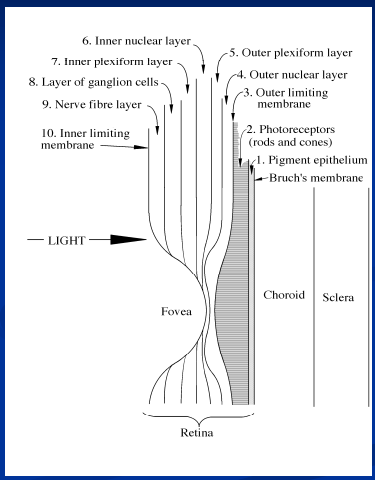
The eye rotates in its socket by the action of six extra-ocular muscles



Retina

The light-sensitive tissue of the eye is the retina.

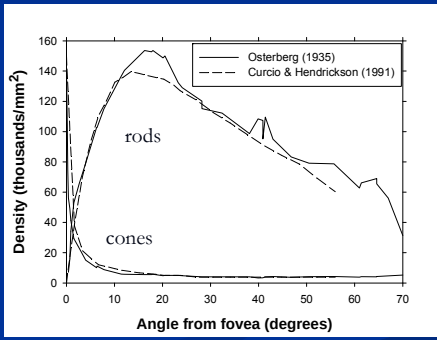
- A number of cellular and pigmented layers and a nerve fibre layer
- Thickness varies from about 100 μm at the foveal centre to about 600 μm near the optic disc.
- A layer of light sensitive cells called photoreceptors at the back of the retina - light must pass through the other layers to reach these cells



Retina (cont.)

The receptor types are the rods and the cones

- The rods associated with vision at low light levels. They reach their maximum density at about 20° from the fovea
- Cones are associated with vision at higher light levels, including colour vision. Predominate in the fovea which is about 1.5 mm across. Their density is a maximum at the pit at the foveola in the middle of the fovea (about 5° from best fit optical axis).



Optical Structure and Image Formation - typical ocular dimensions

Dimensions of the eye vary greatly between individuals

- Some depend upon gender, accommodation and age
- Representative results are shown here.
- Starred values depend upon accommodation:
  - anterior chamber depth
  - lens thickness
  - radii of curvatures of lens surfaces
- Average data have been used to construct schematic eyes.