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CHAPTER 1 ANATOMY AND PHYSIOLOGY

GROSS STRUCTURE OF THE EYE

The eye shares many common anatomical and physiological properties with the brain. Both are protected by bony walls, have firm fibrous coverings and a dual blood supply to the essential nervous layer. The eye and brain have internal cavities perfused by fluids of like composition and under equivalent pressures. As the retina and optic nerve are outgrowths from the brain it is not surprising that the eye and central nervous system are affected by similar disease processes and the physician should constantly be alerted to the many associated conditions.

The eye has three coats, three compartments and contains three fluids.

SLIDE 1

A. The three outer coats of the eye are:

1. Outer fibrous layer
   a) Cornea
   b) Sclera
   c) Lamina Cribrosa

2. Middle vascular layer (uveal tract)
   a) Iris
   b) Ciliary body
   c) Choroid

3. Inner nervous layer
   a) Pigment epithelium of the retina
   b) Retinal photoreceptors
   c) Retinal neurones

B. The three compartments of the eye are:

1. Anterior chamber - the space between the cornea and the iris-lens diaphragm.

2. Posterior chamber - the triangular space between the iris anteriorly, the lens and zonule posteriorly, and the ciliary body laterally.

3. Vitreous chamber - the space behind the lens and zonule.

C. The three intraocular fluids are:

1. Aqueous humour - a watery, optically clear solution of water and electrolytes similar to tissue fluids. Aqueous nourishes the lens and cornea and provides sufficient pressure within the eye to maintain the layers of its wall in firm apposition. The aqueous humour is formed by a process of ultrafiltration from the ciliary capillaries, and then secreted into

the posterior chamber by the ciliary epithelium. The aqueous, which is under continuous production, passes through the pupil into the anterior chamber, and finally out of the anterior chamber at the anterior chamber angle via the canal of Schlemm.

2. Vitreous humour - a transparent gel made up of a three dimensional network of collagen fibrils, the interspaces of which are filled with polymerised hyaluronic acid molecules, capable of holding large quantities of water. It fills the vitreous cavity without any flow. Some aqueous slowly percolates through the vitreous cavity.

3. Blood - in addition to its usual functions, blood contributes to maintenance of intraocular pressure. Most is in the choroid. The choroidal blood flow represents the largest blood flow/unit tissue in the body. The degree of desaturation of efferent choroidal blood is relatively small and indicates that the choroidal vasculature has functions beyond retinal nutrition. It may be that the choroid serves as a heat-exchanger for the retina which absorbs energy as light strikes the retinal pigment epithelium.

D. Clinically the eye may be considered to be composed of two segments:

1. Anterior segment - all structures from (and including) the lens forward.

2. Posterior segment - all structures posterior to the lens.

SCLERA, CORNEA, CONJUNCTIVA, LIDS AND LACRIMAL APPARATUS

A. SCLERA

SLIDE 2

The sclera comprises the posterior five-sixths of the fibrous tunic of the eye. Anteriorly it blends into the regularly arranged lamellae of the cornea. Posteriorly the external two-thirds of the sclera becomes continuous with the dural sheath of the optic nerve, while its inner third becomes the lamina cribrosa, the fenestrated layer of dense connective tissue through which the nerve fibres pass as they leave the eye to enter the optic nerve. The sclera is thickest at the posterior pole (1.0 to 1.3mm) and is thinnest beneath the insertions of the recti muscles (0.3mm). Severe blunt trauma to the globe may lead to its rupture, usually in an area beneath the insertion of a rectus muscle. There are numerous canals (emissaria) passing through the sclera carrying the ciliary nerves and blood vessels to and from the choroid. Malignant melanoma of the adjacent uveal tract may spread into the orbit via these channels.

The sclera is made up chiefly of bundles of collagen fibres, between which fixed cells are sparsely scattered. The fibre bundles are less regularly orientated than is the case in the cornea, interlacing with each other although in general maintaining their long axes parallel to the surface of the globe. The bulk of the sclera is essentially avascular, although its most superficial layer, known as the episclera, is made up of loosely arranged connective tissue with a rich vascular network. Considering its collagenous composition, it is not surprising that the sclera should be involved in collagen diseases eg. rheumatoid arthritis.

Integrity of the sclera is necessary for maintenance of the normal spherical contour of the eye. If an area of sclera is too weak to withstand normal (or elevated) intraocular pressure, a localised outpouching (ectasia) may occur. Such an outpouching is usually lined by the underlying uveal tissue and is termed a 'staphyloma'. Posterior to the ora serrata (the junction of the retina and the ciliary body) a staphyloma will be lined by both choroid and retina.

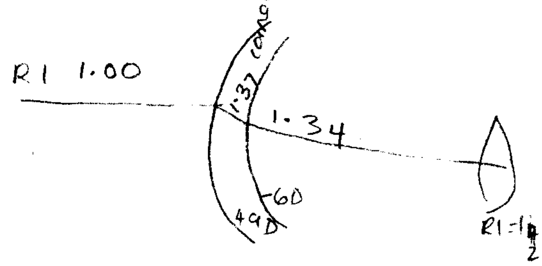
SLIDE 3

B. CORNEA

1. Introduction

The cornea presents a number of interesting peculiarities which adapt it admirably to its primary function, that of refraction and image formation. As you study this unique tissue it is well to keep in mind the requirements it must meet which are:

a) transparency
b) smooth regular surfaces
c) spherical curvature of proper refractive power
d) appropriate refractive index



2. Physiological optics

Both anterior and posterior surfaces of the cornea are very smooth and have nearly perfect spherical curvature at their centres. The refractive index of the cornea is 1.37 and that of the aqueous humour 1.34 (air 1.00, water 1.33). Because the greatest change in refractive index occurs at the cornea-air interface, most of the refraction of light entering the eye takes place here. Actually, refraction takes place chiefly not at the surface of the corneal epithelium per se but rather at the front surface of the thin layer of tears which constantly covers the cornea, providing an even more nearly perfect optical surface.

The conventional unit for expression of refractive power is the dioptre. This is the degree of refraction which brings parallel rays of light to a focus one metre from the refracting surface. The power of the front surface of the cornea is approximately 49 dioptres, so that light rays from infinity would be brought to a focus 1/49 metres or 20.4mm behind it, if no other refracting surfaces were present. As light rays pass from cornea to aqueous, however, refraction again occurs, but this time with divergence rather than convergence of the light rays, since they are moving from a more to a less dense optical medium across an interface which is convex towards the more dense medium. The refractive power of the cornea-aqueous interface is about -6 dioptres.

The rays of light continue to be refracted as they pass through the aqueous, lens and vitreous. The anterior and posterior surfaces of the lens are also very smooth. The radii of curvature are approximately 10mm anteriorly and 6mm posteriorly. The average refractive index of the lens may be considered to be 1.42. Since at the aqueous-lens interface light rays are going from a relatively less to a more dense medium and the interface is convex towards the less dense medium, convergence of the rays will occur. As the rays pass from lens to vitreous, they travel from a more to a less dense medium, but in this case the interface is again convex towards the less dense medium (refractive index of vitreous 1.34) and therefore convergence will again occur. The total refractive power of the lens in situ is approximately +15 dioptres.

3. Structure

SLIDE 5

The cornea has 5 layers (anteroposteriorly):

a) epithelium and basement membrane
b) Bowman's layer
c) stroma
d) Descemet's membrane
e) endothelium

SLIDE 6

a) The epithelium is of the stratified squamous variety with five to six layers of cells in very regular arrangement. The basal cells rest on a basement membrane as a single layer of cylindrical cells. Resting on them are three layers of polyhedral cells and then two layers of flat cells. The most superficial cells have fine microvillous folds which serve to anchor the innermost layer of the tear film, ie. the mucous secretions of the conjunctival mucous glands. In contrast to the skin, the cornea does not show keratinisation. The cells are tightly against one another and there is little or no intercellular fluid. These features are important in maintaining transparency and a smooth surface. A layer of mucus, oil and tears covers and lubricates the anterior surface.

b) Bowman's layer is a homogeneous sheet of modified stroma of uniform thickness beneath the basement membrane of the epithelium, from which it is sharply demarcated. The posterior surface is not sharply defined and merges with the superficial lamellae of the stroma. If Bowman's layer is destroyed it does not regenerate, and an opacity usually results. Occasionally, defects in Bowman's layer may be replaced with epithelium which is transparent.

c) The stroma forms the main bulk of the cornea, comprising 90% of its entire thickness. It consists of three elements, lamellae, cells and ground substance. The lamellae are broad tape-like bands of collagen fibrils extending over the entire width of the cornea, arranged parallel to its surface and packed tightly together. There is little interlacing between lamellae, each remaining at approximately the same depth throughout its course across the cornea. By electron microscopy the individual fibrils are seen to be of uniform size. They are suspended in very regular arrangement in a mixture of glycoprotein ground substance. The long axis of the fibrils in each lamella are parallel to one another and perpendicular to those of adjacent lamellae. The regular arrangement of the collagen fibrils in the glycoprotein ground substance appears to be essential to corneal transparency, the combination perhaps acting as a 'diffraction grating', i.e. a system whereby scattering of light is eliminated by mutual interference from individual fibrils (i.e. they cancel each other out). The ground substance is hydrophilic and is maintained normally in a relatively dehydrated condition, chiefly by an active metabolic 'pump' process located in the endothelium (see below). Any increase in the water content of the cornea leads to disruption of the orderly arrangement of the stroma and accumulation of fluid within and between the epithelial cells ('corneal oedema') with consequent impairment of transparency (SLIDE 82).

The stromal cells are compressed and flattened within lamellar interspaces. Blood vessels and lymphatics are absent. Corneal nerves enter the stroma at the limbus, course in straight radial lines towards the centre of the cornea, then turn to perforate Bowman's membrane and form a plexus immediately beneath the epithelium. They are not easily seen in routine histological preparations. Bare nerve endings beneath and between the epithelial cells provide exquisite sensitivity.

SLIDE 8

d) Descemet's membrane is the basement membrane of the endothelium and is easily stripped from the stroma. In contrast to Bowman's membrane it regenerates after damage, as it is a secretory product of the endothelium.

e) The endothelium is a single layer of cells lining the inner surface of Descemet's membrane. In cross-section the cells are sub-cubical or rectangular. The endothelium and to a lesser extent the epithelium, are only partially permeable, providing a barrier to excessive hydration of the cornea. The endothelium possesses a sodium and bicarbonate 'metabolic pump' which actively removes water from the cornea. Damage or disease of the endothelial cells results in corneal oedema and impaired transparency. While all layers of the cornea are freely permeable to water, the endothelium and epithelium show greater permeability to fat soluble molecules and the stroma to water soluble substances. Drugs most readily able to penetrate the intact cornea are those showing both fat and water solubility.

The metabolic activity of the cornea is located chiefly in the cellular layers, ie. epithelium and endothelium. Metabolites are derived partly from the limbal capillaries, at least in the case of the peripheral cornea. The aqueous humour and the tear film are probably more important sources of metabolites, particularly in the central part of the cornea.

4. Corneal disease

Pathological processes occurring in the cornea are modified by the structural and functional peculiarities of this tissue. The most important of these is avascularity of the normal cornea with lack of lymphatics.This retards healing and favours chronicity of inflammatory processes. Fortunately, the deleterious effect of the lack of blood vessels on the course of inflammatory processes in the cornea is partially offset by its ready accessibility to topical medication. On the other hand, this avascularity permits a high degree of permanent success in homotransplantation (transplantation between individuals of the same species). In other tissues, homotransplantation is rendered more difficult by immune reactions occurring between the donor cells and host antibodies.

SLIDE 61

Corneal transparency

Corneal transparency is affected by minor pathological changes such as oedema or scarring which might be of little consequence elsewhere in the body, but which frequently lead to visual loss. The interaction of these two factors is illustrated well by the course of chronic corneal inflammation which frequently incites vascularisation. As the newly formed vessels reach the diseased tissue, inflammation resolves and healing occurs, but this beneficial effect of corneal vascularisation is negated from a functional stand-point by the scarring and opacification usually occurring in association with it. The presence of blood vessels significantly reduces the chance of successful corneal transplantation.

SLIDE 9

Before proceeding further in the consideration of corneal disease, let us study the conjunctiva and lids, for some knowledge of the intimate inter-relationship of all these structures is required for an understanding of pathological processes in any one of them.

SLIDE 10

C. CONJUNCTIVA

1. Introduction

The conjunctiva (so named because it joins the eye to the lids) is a thin, transparent mucous membrane which covers the posterior surface of the eyelids and is then reflected forward over the anterior surface of the globe to become continuous with the corneal epithelium. Although the conjunctiva is a continuous membrane, it is conveniently divided into three parts:

a) the palpebral or tarsal conjunctiva is firmly adherent to the tarsal plate of the eyelid. Near the posterior edge of the lid margin it becomes continuous with the skin (muco-cutaneous junction).

b) the bulbar conjunctiva covers the globe from the limbus posteriorly for a distance of eight (nasally) to fifteen (temporally) mms. It is transparent and quite freely moveable over the underlying white sclera. The conjunctival epithelium continues as the corneal epithelium at the limbal area. (This explains the common association of conjunctival and superficial corneal disease).

c) the conjunctiva of the fornix consists of the folds which unite the palpebral and bulbar conjunctiva. The conjunctiva in this area is loosely attached to ensure mobility of the globe. The medial fornix contains the plica semilunaris (semilunar fold) and the caruncle. This is the only region of the conjunctival fornix in which there is no real recess or cul-de-sac. The plica semilunaris is a soft moveable fold which corresponds to the third lid or nictitating membrane of certain mammals. Embryologically, the caruncle is that part of the lower lid margin which has been isolated as a result of the development of the inferior canaliculus. Its origin is reflected by the presence of both mucous membrane and cutaneous elements. (Most of these features can be identified on your own eyes).

SLIDE 11

2. Histology

The conjunctiva, like other mucous membranes, consists of an epithelium and a substantia propria.

a) The epithelium is of the stratified columnar variety with two or more layers of cells. Stratified squamous epithelium is present only at the lid margin and near the limbus. Round or oval goblet cells are seen in the superficial epithelial layers near the fornix. The goblet cells are true unicellular mucous glands. Their secretion moistens and protects the conjunctiva and cornea. These cells and the accessory lacrimal glands produce sufficient mucus and tears so that extirpation of the lacrimal gland can be carried out (if, for instance, it contains a tumour) without producing corneal damage from dryness. On the other hand, destruction of the goblet cells (from extensive conjunctival scarring or from Vitamin A deficiency) leads to desiccation of the corneal and conjunctival epithelium (xerosis) in spite of a copious flow of tears. Goblet cells increase in number in conjunctivitis and are responsible for much of the discharge pathognomonic of this condition.

SLIDE 39

b) The substantia propria contains collagenous and elastic tissue, blood vessels, nerves, lymphatic channels and the accessory lacrimal glands. Lymphoid tissue is also present, especially at the fornices where large, follicle-like structures without germinal centres are found.

3. Conjunctival blood vessels

Clinically both the conjunctival and the episcleral (anterior ciliary) blood vessels are visible without magnification. The conjunctival vessels form a prominent branching network, becoming larger as the fornix is approached and are movable with the conjunctiva over the underlying sclera. The episcleral vessels are fixed to the sclera, run radially, and are more numerous in a three to four millimetre wide zone adjacent to the limbus. They become engorged in inflammations of the iris, ciliary body, or cornea, producing a purplish-red ring around the cornea termed '<u>ciliary injection</u> or '<u>ciliary flush</u>' (see SLIDES 48 & 82).

In conjunctival inflammation the dilated vessels are bright red and involve both bulbar and palpebral conjunctiva without special predilection for the circum-corneal area.

SLIDE 12

Attention to the conjunctival vessels during a general physical examination may be rewarding in the case of such diseases as polycythaemia and congestive heart failure, in which the vessels may be dilated and cyanotic. Microaneurysms occur in diabetes, hypertension and in older patients.

Study of the conjunctival blood vessels during life with a microscope is also of considerable interest. The vessel walls are transparent and allow visualisation of the blood elements passing through them. In the larger vessels blood flow is usually rapid and continuous, but in some capillaries velocity is low and inconstant, with the occasional occurrence of transient cessation or reversal of flow. In the absence of disease, some of the small vascular channels in the conjunctiva are normally closed. Aggregation of red cells into clumps ('<u>sludging</u>') occurs in sickle cell disease, the dysproteinaemias, diabetes mellitus, and in any condition associated with marked elevation of the sedimentation rate, but may also be seen in normal subjects.

Another interesting aspect of the conjunctival vessels is the presence of aqueous veins, channels which differ in no way from other small veins except that they carry <u>aqueous humour</u> from the region of Schlemm's canal to the conjunctival circulation. Look for these with the slit lamp during the external examination session.

4. <u>Conjunctival disease</u>

In clinical practice, diseases of the conjunctiva consist chiefly of inflammation (conjunctivitis) and trauma (foreign bodies, chemical burns). Consideration of these will be deferred pending a brief review of the normal anatomy of the lids.

D. <u>THE LIDS AND LACRIMAL APPARATUS</u>

SLIDE 13

1. <u>Histology of the lids</u>

The eyelids are traditionally described as having four layers.

a) The palpebral conjunctiva is very vascular and is firmly adherent to the tarsal plate. Approximately 1-3mm above the upper lid margin there is a broad shallow sulcus, where conjunctival foreign bodies frequently lodge.

b) The tarsal plate (or tarsus) extends across the breadth of each lid, that of the upper being considerably taller (10-12mm) than the lower (5mm). They are about 1mm thick and are made up of dense connective tissue. The tarsus is essential for the normal contour, position and stiffness of the upper lid, but is of less importance in the lower lid.

The Meibomian glands are modified sebaceous glands. They are long and slender, running parallel to one another and perpendicular to the lid margin, each one occupying nearly the entire height and thickness of the tarsus. Their orifices lie in the posterior one half of the lid margin, just anterior to the junction between the conjunctival mucous membrane and the squamous epithelium of the skin (mucocutaneous junction). The upper lid contains 30-40 glands and the lower 20-30. The oily secretion of the glands forms a layer on the lid margins which prevents the tears from spilling over them, and provides the superficial oily layer of the precorneal tear film. When distended with their secretion, the glands can be seen through the overlying conjunctiva of the everted lid as yellowish streaks.

c) The orbicularis muscle, innervated by the seventh cranial nerve, serves to close the lids.

d) The skin and subcutaneous tissues of the lids are very thin, the former frequently becoming inelastic, pendulous and folded in old age. The subcutaneous tissue has little fat, a feature which makes the skin of the eyelid particularly suitable for full thickness grafting.

The lid margin is about 2 mm wide and is divided into anterior and posterior halves by the gray line, a faint line just anterior to the orifices of the Meibomian glands. A surgical incision here splits the lid into an anterior cutaneous and muscular portion containing the cilia and a posterior conjunctival and tarsal portion, and is used extensively in plastic repair of the lids after excision of tumours.

SLIDE 14

The cilia arise from hair follicles located in connective tissue just anterior to the tarsus.

The <u>glands of Zeis</u> are sebaceous glands like the Meibomian glands but much smaller. Their ducts open into the hair follicles of the cilia.
The <u>glands of Moll</u> are large apocrine glands opening on to the lid margin between the cilia or into their follicles.
The <u>levator palpebrae superioris</u> muscle, which arises at the apex of the orbit just above the superior rectus and accompanies that muscle through the orbit, inserts into the skin of the upper lid and indirectly into the tarsus and the superior conjunctival fornix. It is innervated by the third cranial nerve, and by the sympathetic system to its deep portion.

<u>The accessory lacrimal glands</u> are of essentially the same structure as the lacrimal glands. Two groups are present, the more important lying in the conjunctival mucosa near the fornices (glands of Krause). A few similar accessory lacrimal glands are situated near the upper border of the superior tarsus (glands of Wolfring).

The <u>superior and inferior palpebral arterial arcades</u> are large vessels running parallel to the lid margins about 2 mm from them.

SLIDE 38

2. <u>The Lacrimal Apparatus</u>

Tears collect at the nasal edge of the palpebral fissure and pass through two small ducts called <u>canaliculi</u> into the <u>lacrimal sac</u>. The openings of these ducts at the nasal edge of each lid margin are visible grossly. The lacrimal sac terminates in the <u>nasolacrimal duct</u> which leads to the inferior meatus of the nose.

The lacrimal gland occupies the superior temporal anterior portion of the orbit and its ducts empty into the palpebral conjunctiva several millimetres above the upper border of the tarsus.

3. <u>Function of the lids and lacrimal apparatus - precorneal tear film</u>

The lids play an important role in protecting the eye from mechanical trauma, extremes of temperature and bright light. Their normal function is essential in maintaining the normal precorneal tear film, which is itself of paramount importance for corneal health and transparency. The tear film is made up of three layers, <u>mucoid</u> adjacent to the epithelium (from the goblet cells), <u>watery</u> anterior to this (from the lacrimal and accessory lacrimal glands) and <u>oily</u> superficially (from the Meibomian glands). The tears have a relatively high protein content (0.7%), leading to low surface tension and allowing more perfect wetting of the corneal surface.

The tears flow slowly down across the cornea, and accumulate in the angle formed by the margin of the lower lid and the globe. They then flow nasally to the inferior punctum and from there into the nose. The upper lid acts as a 'windscreen wiper', keeping the tear film spread over the entire cornea. The tears contain lysozyme (an enzyme which inhibits bacterial growth).

The normally hypertonic tears play a small but occasionally crucial role in the maintenance of corneal deturgescence and transparency. Their hypertonicity is maintained in part by evaporation of the tear film.