

Applied Physiology of the Eye

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APPLIED PHYSIOLOGY OF THE EYE

PREFACE

HAVING been associated with the study, practice and teaching of ophthalmology for a period extending over forty years, I have written this book in the endeavour to help those who are working for higher examinations in ophthalmology such as the F.R.C.S. in ophthalmology, the Mastership of Surgery in ophthalmology and the Diploma of Ophthalmology. I have also had in mind those who although having been in ophthalmic practice for many years wish to keep up to date in matters connected with physiology.

I have endeavoured to marshal together within the compass of a small book the main facts relating to the physiology of the eye and of those organs which have a direct or indirect physiological connexion with the function of vision. These facts have had to be gathered from a large number of sources, for ophthalmology has extensive relations with so many branches of medicine, surgery and pathology.

It must ever be kept in mind that the optic nerve with the retina is an outgrowth of the brain and is therefore, an integral part of the central nervous system, so that the use of the ophthalmoscope is frequently valuable in aiding the diagnosis of certain diseases of the central nervous system and also of some morbid conditions of other organs; moreover the careful examination of the eye and its appendages is frequently an aid in the diagnosis of many general diseases.

The eye has intimate connexions with the autonomic nervous system and through the extrinsic ocular muscles it has association with the proprioceptive system, of which the cerebellum is the head ganglion.

It also has connexions with the circulatory system, particularly with the capillaries. The morbid changes which occur in the cardio-vascular system frequently affect the visual organ.

The eye as part of the organism becomes affected by the biochemical processes of tissue metabolism and also by the hormones of the endocrine organs.

By its sheltered position in the orbit, the margin of which is somewhat thickened for the purpose of protection, the eye usually escapes direct injury except by a perforating wound,

but, it sometimes becomes affected by those gross changes which occur in the adjacent structures such as the cavernous sinus, the maxillary antrum, the frontal and ethmoidal sinuses and the nasopharynx.

A list giving the Greek derivation of certain words relating to ophthalmic and allied conditions has been included and also a list of those whose names are associated with certain ophthalmic diseases or syndromes.

In the preparation of this work the constant and invaluable assistance of my son, T. Keith Lyle, C.B.E., M.A., M.D., M.Chir., M.R.C.P., F.R.C.S., has been available to me. He has made many important alterations and additions so that it is right that his name should appear on the title-page. I am also indebted to Theodore H. Whittington, M.D., M.R.C.P., D.O.M.S., and to M. Hugh M. Ryan, M.B., B.S., F.R.C.S., D.O.M.S., for their great interest and for many suggestions which also have been included in the text.

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The manuscript of this book had only just been completed when my father died in March 1956, so that it has fallen to my lot to correct the proofs and to make such alterations as were necessary to bring the text up to date. In this I have had the valuable assistance of Kenneth C. Wybar, M.D., Ch.M., F.R.C.S., and Calbert I. Phillips, M.B., F.R.C.S., the latter having been entirely responsible for the preparation of the Index. I acknowledge their help with grateful thanks.

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Chapter 1

THE EYELIDS AND ADJACENT STRUCTURES

The Eyelids

THE upper and lower eyelids are composed of the following tissues:

1. The integument, which is thin and contains small sweat and sebaceous glands.

2. Loose subcutaneous areolar tissue free from fat; the looseness of the subcutaneous tissue predisposes to œdema (chemosis) when the area becomes injured or infected.

3. The orbicularis palpebrarum, some of the fibres of which pass mesialwards and become attached to the lacrimal fascia and to the upper portion of the posterior lacrimal crest of the lacrimal bone; these fibres constitute the *pars lacrimalis* (the tensor tarsi or muscle of Horner). A small fasciculus of the orbicularis palpebrarum courses close to the margin of each eyelid, constituting the *pars marginalis* (the ciliary bundle or muscle of Riolan); the function of this muscle is to keep the eyelids closely applied to the eyeball.

4. A layer of Meibomian (tarsal) glands which lies within the tarsal plate. These are modified sebaceous glands and secrete a fatty substance which lubricates the margins of the eyelids and, in ordinary circumstances, prevents the lacrimal secretion from overflowing.

5. The tarsal plate with the septum orbitale. The tarsal plates consist of fibrous and elastic tissue, that of the upper eyelid is somewhat D-shaped with the straight margin lowermost, that of the lower eyelid is an elongated band chiefly of fibrous tissue, and not so well defined as the tarsal plate of the upper eyelid, to which the levator palpebræ is attached.

6. The palpebral conjunctiva in which there are small nodules of lymphoid tissue. This lymphoid tissue becomes infiltrated in certain cases of conjunctivitis, especially in trachoma (granular ophthalmia).

By the contraction of the orbicularis palpebrarum the palpebral aperture becomes closed mesialwards so that foreign bodies

in the conjunctival sac tend to be passed towards the medial canthus in the lacrimal secretion.

In the connective tissue of the upper eyelid there are plain muscle fibres which constitute the superior palpebral muscle of Müller, innervated by the sympathetic nerve. These muscle fibres also are attached to the upper border of the tarsal plate.

The plain muscle of the lower eyelid is thinner than that of the upper eyelid; it is attached posteriorly either to the sheath of the inferior rectus muscle or to the expansion of that sheath to the sheath of the inferior oblique muscle, and attached anteriorly to the ocular conjunctiva and to the lower eyelid.

In some aged persons there may be seen a swelling in the upper eyelid near the medial canthus; the swelling is a hernia of orbital fat and is referred to as "bourrelet senile," it is caused by local atony of the orbicularis palpebrarum.

The extremities of the tarsal plates are prolonged to form the mesial and lateral tarsal (or palpebral) ligaments by which the tarsal plates are attached to the middle of the corresponding margins of the orbit. The mesial tarsal ligaments split to embrace the lacrimal sulcus. The anterior limbs of the mesial tarsal ligaments of the upper and lower tarsal plates fuse to form the tendo oculi (the medial palpebral ligament). The tendo oculi is a broad band of fibrous tissue which is attached to the anterior lacrimal crest of the frontal process of the maxilla and some of its fibres are attached to the lacrimal fascia which covers the fundus of the lacrimal sac. The upper portion of the tendo oculi is thin so that the fundus of a distended lacrimal sac bulges forward in that position, although the main swelling is below the tendo oculi.

The close connexion of the anterior limb of the mesial palpebral ligament with the lacrimal fascia and lacrimal sac has an important bearing; a blow upon the eyelids may cause rupture of the lacrimal fascia and lacrimal sac through the sudden tension of the medial palpebral ligament, with the result that on "blowing the nose" air may be forced into the connective tissue of the eyelids resulting in local surgical emphysema.

The Lacrimal Caruncle. The lacrimal caruncle, structurally and developmentally, is a portion of the medial margin of the lower eyelid which has become detached and modified in

structure due to the development upwards of the lower lacrimal canaliculus.

The lacrimal caruncle is situated in the lacus lacrimalis; its surface is a stratified epithelium with a few hairs. In the deeper connective tissue there are modified sebaceous glands and plain muscle fibres. About the middle of the caruncle there are one or two small tubulo-acinar glands which resemble in structure the accessory lacrimal glands of Krause, present mainly in the upper conjunctival fornix.

The lacrimal caruncle is in close relationship with the fascial expansion of the medial rectus muscle so that after a recession or a tenotomy of that muscle the caruncle becomes retracted, unless the fascial bands uniting the muscle sheath to the superjacent caruncle are divided.

The sensory nerve of the lacrimal caruncle is the infra-trochlear branch of the nasociliary nerve.

Epicanthus. This is a semilunar fold of skin which may cover the structures present at the medial canthus; it is usually bilateral. The fold of skin is continuous with the bridge of the nose, which is usually unduly flat, and the palpebral apertures are somewhat obliquely set. In some cases there is bilateral ptosis. Bilateral epicanthus, with the palpebral apertures set obliquely upwards and lateralwards, occurs in the Mongolian race and the name *mongolism* is applied to a condition characterized by these physical features. The affected children are usually dwarfed and mentally defective, the tongue is large and somewhat fissured and the thumbs are generally short. Lenticular opacities are frequently present.

The Muscles of the Eyelids. The *orbicularis palpebrarum* is a thin striped muscle which covers the circumorbital region and is continued into the eyelids. The fasciculi of the muscle are arranged concentrically with the palpebral aperture.

The muscle consists of an orbital and a palpebral portion: the *orbital* portion extends on to the eyebrow, the temple and the cheek. These orbital fibres come into action when the eyelids are forcibly closed.

The *palpebral* portion enters into the formation of the eyelids and is situated in front of the septum orbitale and the tarsal plates. The preseptal fibres are present in front of the lacrimal fascia which covers the lacrimal sac; these fibres constitute the anterior lacrimal muscle of Gerlach. The pretarsal fibres give

rise to fibres which pass behind the lacrimal sulcus and are attached to the upper portion of the posterior lacrimal crest of the lacrimal bone; these fibres constitute the tensor tarsi, or muscle of Horner.

There is a small fasciculus of the palpebral portion of the orbicularis palpebrarum near the margin of both eyelids which constitutes the pars marginalis or ciliary bundle (muscle of Riolan). This muscle keeps the eyelids closely applied to the eyeball. When the muscle fibres of the lower eyelid lose their tone, as sometimes occurs in elderly persons, *senile ectropion* results and when these muscle fibres become paralysed, as in facial paralysis, *paralytic ectropion* results. In both cases there is an accompanying epiphora. When these muscle fibres overact *spasmodic* or *spastic entropion* is caused.

In some cases there occurs a loss of tone of the orbicularis palpebrarum during sleep, the result of which is *lagophthalmos*.

The *levator palpebræ superioris* is a flat muscle which arises from the under surface of the smaller wing of the sphenoid bone above the annulus of Zinn and immediately above the origin of the superior rectus (see Fig. 15). The muscle ends in an expanded tendon—the levator palpebræ aponeurosis—situated behind the supra-orbital margin and arching over the eyeball. The anterior edge of the aponeurosis gives rise to fibres attached to the skin of the upper eyelid, the lateral extremities of the aponeurosis are attached to the medial and lateral portions of the orbital margin.

The fibres which are inserted into the skin arch over the anterior surface of the tarsal plate and traverse the horizontal fasciculi of the orbicularis palpebrarum. The lateral extremity of the aponeurosis subdivides the lacrimal gland which becomes folded round its posterolateral border. The lateral extremity of the aponeurosis is attached to the orbital tubercle on the zygoma (malar bone). The mesial extremity of the aponeurosis joins with the mesial palpebral (tarsal) ligament. Directly beneath the aponeurosis of the levator palpebræ is the superior palpebral muscle of Müller attached to the upper border of the tarsal plate. By its fascial sheath the levator palpebræ is attached to the conjunctiva in the upper fornix. This helps to maintain the fornix when the eyes are elevated.

The Innervation of the Eyelids and Eyebrows. The *motor*

nerves to the eyelids and eyebrows are the oculomotor and the facial. The oculomotor by its superior division supplies the levator palpebræ; and the facial through its temporofacial division supplies the orbicularis palpebrarum, the frontalis and the corrugator supercilii.

The *sensory* nerves are from the ophthalmic and maxillary divisions of the trigeminal nerve. The ophthalmic division gives rise to the lacrimal, the supra-orbital, the supratrochlear and the infratrochlear nerves: the supra-orbital and supratrochlear nerves are branches of the frontal nerve, and the infratrochlear is a branch of the nasociliary nerve. The maxillary division gives rise to the zygomaticofacial, and to the infra-orbital, which is distributed to the lower eyelid.

The *autonomic* nerves supply the plain muscle in the upper and lower eyelids, the blood vessels and the glands.

Closure of the Palpebral Aperture. Closure of the palpebral aperture by movements of the eyelids may be initiated reflexly (blinking), automatically (winking) and in a voluntary manner. The automatic act serves to keep the cornea moistened, while the approach of, or the contact of, a foreign body causes a reflex contraction of the eyelids in which the orbicularis palpebrarum functions. This latter movement is initiated by stimulation of a branch of the ophthalmic division of the trigeminal nerve. The *afferent* impulses arrive at the nucleus of the trigeminal nerve present in the pons, which is connected with the nuclei of the oculomotor and facial nerves through the posterior longitudinal bundle (*see* Fig. 12). This nervous interplay accounts for the elevation of the eye which occurs simultaneously with eyelid closure. The *efferent* impulses traverse the facial nerve to the orbicularis palpebrarum.

Retraction of the Upper Eyelid. The upper eyelid usually rests 1 to 3 mm. below the limbus corneæ. In cases of eyelid retraction the upper eyelid rests at or above the level of the upper margin of the iris base and in some cases the sclera may be observed above the corneoscleral junction.

Retraction of the upper eyelid upon downward movement of the eyeball sometimes occurs after incomplete recovery of oculomotor paralysis.

Constant retraction of the upper eyelid, causing a wide palpebral aperture with exophthalmos, is characteristic of primary thyrotoxicosis (Parry's or Graves's disease).

Ptosis. Ptosis (drooping) of the upper eyelid may be of congenital or acquired origin.

Congenital ptosis is usually bilateral although often unequal and is due either to defective development of the oculomotor nuclei, or to defective development of the levatores palpebrarum. If the defect is of muscular origin, the superior rectus may also be involved. Congenital ptosis may be associated with epicanthus.

Slight unilateral congenital ptosis may be associated with *jaw-winking*, the levator palpebræ on the side of the ptosis becoming unduly active during mastication. This synkinesis occurs upon opening the jaw and upon lateral movements of the mandible, due to the action of the pterygoid muscles—and this constitutes the Marcus Gunn syndrome.

Acquired ptosis may be due either to paresis or paralysis of the oculomotor nerve, or to injury of the branch of the oculomotor nerve to the levator palpebræ, or it may be caused by injury to that muscle. In some cases the drooping of the upper eyelid is due to loss of tone of the superior palpebral muscle of Müller caused by sympathetic paralysis, and in such a case there may be other signs of sympathetic paralysis namely meiosis and slight enophthalmos. Compensatory overaction of the frontalis muscle is frequently present in a patient affected with ptosis.

Transient ptosis and diplopia, due to pareses of the extrinsic ocular muscles, are usually early symptoms of myasthenia gravis (*see p. 142*), and these become more marked as the disease progresses.

Ptosis, sometimes unilateral but more usually bilateral, is frequent in cases of encephalitis lethargica (a disease probably due to a neurotropic virus) in which there may also be ophthalmoplegia externa (*see Chapter 24*), due to midbrain lesions.

Ptosis is a rare symptom in cases of Friedreich's ataxia in which nystagmus is sometimes present (*see p. 155*).

The Eyebrows

Each eyebrow consists of thick skin in which there are somewhat long and thick hairs. The hairs of the eyebrows and eyelashes are amongst the most sensitive organs of the body and aid in protecting the eyeball. The hairs of the eyebrows are particularly responsive to pressure stimuli. This is due to the presence of large end-bulbs connected with the sensory nerves

in the region of their roots. In cases of alopecia areata of the scalp the eyelids may become devoid of eyelashes.

Beneath the skin of the eyebrow is a layer of striped muscle, some of the fibres of which end in the skin. Beneath the muscular layer is a layer of loose connective tissue which contains fat in the meshwork. Deeper still is the epicranial aponeurosis firmly attached to the supra-orbital margin. Beneath the epicranial aponeurosis is a layer of loose connective tissue and the periosteum.

The muscular layer of the eyebrow consists of three sets of fasciculi: fibres of the frontalis muscle (the anterior portion of the occipitofrontalis) directed vertically, fibres of the corrugator supercilii directed obliquely and fibres of the orbital portion of the orbicularis palpebrarum directed concentrically. These three sets of fibres traverse the superficial fascia and become attached to the skin of the eyebrow.

Forced contraction of the frontalis muscles causes the eyebrows to become elevated and the skin of the forehead to be transversely wrinkled. When the corrugator supercilii muscles overact the skin of the forehead becomes drawn into vertical wrinkles.

The frontalis, the corrugator supercilii and the orbicularis palpebrarum are innervated through the facial nerve, but it is probable that nerve fibres from the oculomotor nucleus pass through the posterior longitudinal bundle to the facial nerve nucleus and, by way of the facial nerve, innervate these muscles. In cases of facial nerve paralysis of cortical origin, the muscles of the lower facial group (those of the nose, cheek and mouth) become involved, but the muscles of the upper facial group (frontalis, corrugator supercilii and the orbicularis palpebrarum) usually escape. In cases of facial nerve paralysis of nuclear origin, both groups of muscles become involved.

The eyebrows aid in shielding the eyes from intense rays of light, they also prevent sweat from the brow trickling into the conjunctival sac.

The frontalis portion of the occipitofrontalis, the orbicularis palpebrarum and the corrugator supercilii have been grouped together as the "accessory muscles of accommodation". These muscles contract when the ciliary muscle is contracting in an excessive manner. The ciliary muscle is innervated by the parasympathetic part of the oculomotor nerve, and the frontalis,

orbicularis palpebrarum and the corrugator supercilii are probably innervated from the oculomotor nucleus through fibres in the facial nerve.

In cases of so-called "eye-strain", that is "*ocular fatigue*", pain is sometimes referred to the occipital region and to the back of the neck; this may be explained by the connexion of the occipitalis portion of the occipitofrontalis muscle with the deep cervical fascia at the back of the head.

The corrugator supercilii causes vertical wrinkling of the skin of the forehead, which frequently occurs during forced accommodation and also on exposure of the eyes to intense light.

The Conjunctiva

The *palpebral* conjunctiva covers the ocular surface of the tarsal plates and the Meibomian glands, and it extends into the supra- and infra-tarsal regions before becoming reflected upon the eyeball. Fibres of the levator palpebræ superioris are attached to the conjunctiva at the upper conjunctival fornix.

The *ocular* or *bulbar* conjunctiva is reflected over the anterior third of the eyeball. It is separated from the eyeball by the capsule of Tenon (fascia bulbi) with which it blends at about 3 mm. from the corneal margin. The ocular conjunctiva is loosely attached to the subconjunctival tissue and it is in this tissue that œdema (chemosis) readily occurs. Subconjunctival hæmorrhages sometimes result when the capillary blood pressure becomes unduly raised, but they may occur quite spontaneously, particularly in elderly persons. These hæmorrhages retain their bright red colour because oxidation of the hæmoglobin readily occurs through the thin conjunctiva.

A severe blow upon the forehead or temple may result in blood entering the orbit through the inferior orbital (sphenomaxillary) fissure and cause subconjunctival and subpalpebral extravasation of bright red blood.

The innervation of the conjunctiva. This is derived from the supratrochlear nerve, the infratrochlear branch of the nasociliary nerve, and the lacrimal nerve (branches of the ophthalmic division of the trigeminal nerve); also from the palpebral branches of the infra-orbital nerve (a branch of the maxillary division of the trigeminal nerve).

Cocaine hydrochloride (4 per cent. solution) when instilled into the conjunctival sac has a paralysing effect upon the

sensory nerve endings; it also causes contraction of the superficial arterioles by potentiating the action of "sympathin", an adrenaline-like substance (sympathetic action). When the solution of cocaine is combined with a solution of adrenaline (1 in 1000) the local action of the cocaine is further increased because absorption of the cocaine is prevented by the contraction of the peripheral arterioles, brought about by the action of the adrenaline.

Pigmentation of the conjunctiva. Dark brown staining of the epithelium of the conjunctiva especially in the lower fornix, also of the caruncle and of the deeper portion of the cornea, is caused by the prolonged use of solutions of silver nitrate, argyrol and protargol, or sometimes by absorption of silver particles in dust in certain industries, i.e. *argyrosis*. Pigmentation due to the presence of particles of iron in the corneal epithelium sometimes occurs, i.e. *siderosis*. Particles of copper may be present in the corneal epithelium following injury by foreign bodies of copper, also by the prolonged use of copper sulphate in cases of trachoma, causing *chalcosis*.

In cases of Addison's disease, a condition of adrenal insufficiency, the conjunctivæ and the eyelids sometimes become pigmented (*see p. 218*).

Pinguecula conjunctivæ is a small yellowish raised triangular patch on the ocular conjunctiva in the line of the palpebral aperture; it usually appears first on the nasal side, later on the temporal side, of the cornea. Its formation is due to hyaline degeneration of the subconjunctival connective tissue and to the substitution of yellow fatty tissue for white fibrous tissue. In some cases of lipidosis, in which the tissues contain fatty acids as integral parts of their molecules, the pingueculæ are of a distinct brownish-yellow colour.

Lipidosis occurs in cases of Gaucher's disease in which the *pingueculæ* are of a brownish-yellow colour and there are areas of brown pigmentation on the face, forehead, arms and legs.

Gaucher's disease is a rare congenital and familial condition in which there are deposits of glycolipides in the reticulo-endothelial cells of the spleen, causing splenomegaly, also in the liver, causing hepatomegaly; there is also leucopenia.

The glycolipides (galactosides or cerebrosides) are compounds of the carbohydrate galactose with a fatty acid and an organic base sphingosine, a complex nitrogenous substance.

Pterygium is a triangular vascular thickened patch of ocular conjunctival tissue which starts on the nasal side of the cornea and later encroaches upon and becomes adherent to the cornea. The pterygium appears to be the result of chronic irritation due to the presence of dust or sand, which results in a local proliferation of connective tissue containing elastic fibres which is in continuity with the subconjunctival tissue.

The Lacrimal Gland and the Lacrimal Passages

The Lacrimal Gland. This consists of two portions, the upper or orbital lobe situated in the lacrimal fossa and the lower or palpebral lobe present under the conjunctiva. The orbital lobe is the larger lobe, situated above the aponeurosis of the levator palpebrae, the palpebral lobe is below the aponeurosis.

Tumours of the lacrimal gland cause the eyeball to become displaced downwards and forwards.

The Lacrimal Secretion. This secretion keeps the surface of the cornea moist and free from particles of dust, it is also an efficient bactericide. It is slightly alkaline and consists of water 98.2 per cent. and solids 1.8 per cent. Of the solids 0.5 per cent. is protein and 1.3 per cent. inorganic salts, sodium chloride being the most abundant. The chloride content varies between 0.9 per cent. and 1.25 per cent. There are traces of sodium bicarbonate and alkaline phosphates present. The osmotic pressure of the lacrimal secretion is about equal to 0.9 per cent. of sodium chloride. The lacrimal secretion contains an enzyme, lysozyme, which has the function of killing and dissolving bacteria (A. Fleming, 1933), thus protecting against infection. This natural antibacterial substance appears to be widely distributed throughout the body.

The Innervation of the Lacrimal Gland. (1) *Afferent impulses.* The lacrimal nerve, a branch of the ophthalmic division of the trigeminal, conveys afferent impulses to the brain-stem. These afferent impulses may be initiated by a movement caused in the lacrimal gland by the act of blinking. Other fibres of the trigeminal convey afferent impulses to the brain-stem which result in the reflex secretion of tears. Drying of the cornea and stimulation of the cornea or conjunctiva by a foreign body cause a reflex secretion. A reflex secretion also occurs when the cornea is exposed to infra-red (heat) rays, also when the retina