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# NUTRITION AND THE EYE

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## Anatomy and physiology of the eye from the point of view of its nutrition

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Fig. 1 illustrates diagrammatically the meridional (i.e. antero-posterior) section of a human eye; from most aspects it is profitable to consider the eye as being made up of three coats—protective, vascular and neuro-epithelial—forming a cavity in which are contained the aqueous humour, lens and vitreous body.

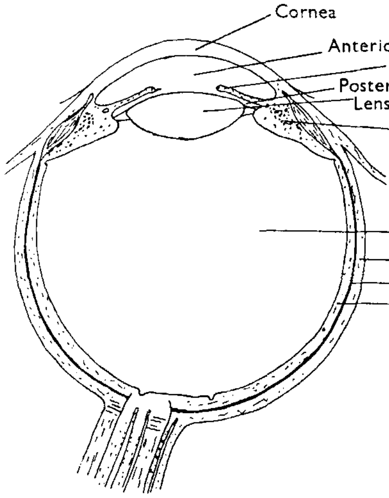


Fig. 1. Diagrammatic presentation of the meridional (antero-posterior) section of the human eye.

*Protective coat.* This, the outermost coat, consists of the transparent cornea and the opaque sclera; their curvatures are different, and the region of junction is called the limbus or limbal region. The cornea is a living structure, containing cells—corneal corpuscles—and being lined by epithelium and endothelium, so that its nutrition is a matter of concern for us at this meeting. By contrast, the sclera is composed essentially of collagen fibrils and presents no obvious nutritional problem.

*Vascular coat.* Crudely speaking, we may regard the choroid, ciliary body and iris as constituting the middle or the vascular coat. A series of posterior ciliary arteries puncture the globe around the entrance of the optic nerve and travel forward in the choroid, which is a purely vascular layer with a minimum of connective tissue. Most



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of them break up into capillaries to form a capillary layer—the chorio-capillaris—that serves to nourish the retina lying immediately beneath. Other arteries continue forward to the ciliary body where they anastomose with anterior ciliary arteries entering the globe near the limbus. Together they form the major circle of the iris, from which vessels pass to supply blood to the various structures within the iris and ciliary body.

*Inner layer*. The function of the middle coat becomes apparent when we consider the innermost layer of the eye—its retina, which extends from the posterior pole up to the ciliary body. Nutrition of the outer layer of the retina—pigment epithelium, rods and cones and bipolar cells—is achieved by diffusion from the capillary layer of the choroid. The innermost layer, that containing the ganglion cells, is nourished mainly by a separate circulation—the retinal circulation—the capillaries of which are derived from the central artery of the retina which enters the eye in the optic nerve. Thus the retina is well supplied with blood, but even this double supply seems inadequate so that indirectly the aqueous humour, as we shall see, also contributes.

The retina extends as far forward as the ciliary body; beyond it the inner layer of the eye becomes the ciliary epithelium, a double layer of cells that covers this body, and the posterior epithelium of the iris. The ciliary body has been looked upon, for our present purposes, as a part of the vascular coat; however, it contains the ciliary muscle concerned with accommodation, and its epithelial covering is of vital importance from a nutritional aspect since it is considered that the aqueous humour is secreted by the cells of the inner layer. Because the lens and cornea are avascular, the nutrition of these bodies is achieved by the circulation of aqueous humour which carries oxygen, sugar and amino acids to them and carries away excess carbon dioxide and lactate. By circulation of aqueous humour I mean a continuous secretion of the fluid by the epithelium into the posterior chamber where it is driven through the

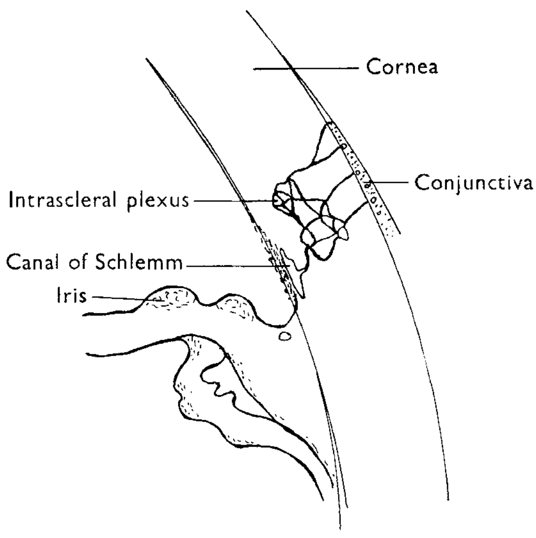


Fig. 2. Diagrammatic presentation of structures involved in the circulation of aqueous humour in the human eye.

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pupil into the anterior chamber to be drained away into Schlemm's canal, whence it is carried into the blood vessels of the intrascleral plexus (Fig. 2). The pressure within the eye—the intraocular pressure—is determined in the long run by the rate of secretion of aqueous humour and the resistance to outflow offered by the meshwork of trabecular tissue in the angle of the anterior chamber which separates the wall of Schlemm's canal from the fluid in the anterior chamber. There seems little doubt that a pathologically raised intraocular pressure—glaucoma—can result from sclerotic changes in the trabecular meshwork. From a nutritional point of view the effects of argemone oil, or its essential principle—sanguinarine—are of concern here. According to Lloyd (1955) and Leach (1955) the glaucoma that results from eating this oil is associated with hyperplasia of the endothelial covering to the trabeculae, a condition that might well obstruct flow between the meshes of the tissue.

*The lens.* Besides serving to maintain the intraocular pressure, the aqueous humour is also concerned with nutrition of the lens and cornea. Because of its situation, completely insulated from the vascular system, the lens relies exclusively on the aqueous humour for nutrition, whereas the dependence of the cornea is only partial because the blood vessels of the conjunctiva come into close relationship with the peripheral region at the limbus. The lens is a tightly packed mass of transparent fibrous cells, enclosed in a capsule. Throughout life the number of these fibres increases because the cells of lens epithelium—a layer of cells on the anterior surface of the body—are able to divide mitotically and elongate to become new fibres. Nutrition of this body is therefore an important consideration, and it is not surprising that dietary deficiencies may cause changes in the lens. Alterations in the lens, whether they be the effects of age, of trauma, of poisons, of radiation, or of diet are manifest usually as the loss of transparency, often localized to a definite region; the name cataract is applied to this opacity or loss of transparency. The importance of the aqueous humour in the nutrition of the lens is revealed by a study of the concentration of glucose in the fluid, which is always less than that of the plasma. Removal of the lens allows the concentration to rise, but not to the plasma value, partly because the cornea also utilizes glucose, but mainly because the retina also draws on the aqueous humour. Thus the concentration of glucose is considerably lower in the vitreous body than it is in the aqueous humour; if the plasma concentration is taken as 100, the values for aqueous humour and vitreous body are 79 and 45 respectively. This means that, in spite of its double vascular supply, the retina utilizes glucose so rapidly that the concentration in the fluid immediately adjacent to it—the vitreous body—can never rise to that in the plasma; in consequence, there is a gradient of concentration between aqueous humour and vitreous body leading to the passage of glucose from the one to the other.

*The cornea.* The transparent portion of the outer coat consists (Fig. 3) of an outer epithelium, consisting of about six layers of cells, an inner endothelium, consisting of a single layer of cells, and a stroma or substantia propria sandwiched between and consisting of lamellae built up of well-orientated collagen fibres. Immediately beneath the epithelium and endothelium there are Bowman's membrane and Descemet's membrane, two non-cellular layers. Scattered between the corneal

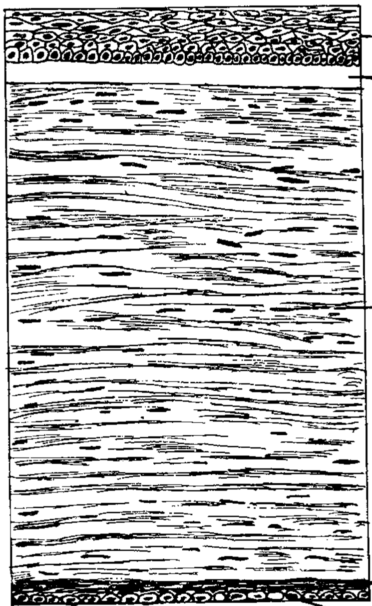


Fig. 3. Diagrammatic presentation of the transparent coat of the outer portion of the cornea of the human eye.

lamellae there are numerous corneal corpuscles, the equivalent of fibroblasts in other connective tissues. As indicated earlier, nutrition of the cellular elements of the cornea is brought about by the aqueous humour and the blood vessels of the conjunctiva which terminate just at the corneo-scleral junction. In addition, oxygen may be derived from the atmosphere or, when the lids are closed, from the vessels of their conjunctival linings. The collagen fibres of the stroma are well coated with mucoid which imparts to the stroma as a whole a strong tendency to imbibe fluid which has to be resisted by active-transport mechanisms. Thus, if the eye is excised and kept at 4° the cornea swells through imbibition of aqueous humour and loses its transparency. On warming the eye to 31° (the normal corneal temperature) the water is driven out and the cornea recovers its transparency. Thus the normal state of hydration—and thence the normal transparency—is maintained by the metabolism of the cellular structures—probably epithelium and endothelium—so that interference with the nutrition, in so far as it restricts the supply of metabolic energy, may cause a corneal oedema.

A more localized form of opacity may result from mechanical or chemical injury to the epithelium and underlying corneal lamellae; new epithelium covers the wound, by spread of existing layers and by regeneration, whilst corneal corpuscles move in and lay down new collagen fibres. If they are not laid down with sufficient regularity, the transparency, which depends on an accurate mutual orientation of the fibres, is lost, and the opaque spot is called a leucoma.

A remarkable characteristic of the conjunctival vessels at the limbus is their power of growing into the corneal tissue in response to damage or nutritional stress;

this corneal vascularization may be regarded as a means of supplementing the nutritional supplies of the cornea under stress, but the mechanism whereby this growth, and subsequent dying away, of the vessels is brought about is not known.

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## The biochemistry of the eye

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The parts of the eye are diverse in embryological origin, in form, in function and in their biochemistry. This paper can only briefly survey a few aspects of ocular biochemistry, particularly those related to nutrition that are not being examined by other contributors to the Symposium.

### *The cornea*

The cornea has two main and quite separate layers, the epithelium which has an active metabolism and contains the enzymes and coenzymes necessary for glycolysis and for oxidation of glucose through the pentose-phosphate and the citric-acid cycles (Kinoshita & Masurat, 1959) and the corneal stroma which contains a few cells and consists mainly of criss-crossing layers of collagen fibres embedded in a mucoprotein and mucopolysaccharide matrix.

The cornea is avascular and the oxygen required for respiration of the epithelial cells diffuses into the tissue from the blood vessels of the conjunctiva and from the aqueous humour, from the air when the eye is open or from the vessels of the lids when the eye is closed. If respiration of the epithelial cells is impaired the cornea becomes hydrated and transmission of light is upset. Smelser (1952) and Smelser & Chen (1955) showed that if respiration of the corneal epithelium was inhibited by the fitting of a contact lens, the cornea became waterlogged, swollen and less transparent and the lactic-acid content of the tissue doubled within 3 h. But if a bubble of oxygen was trapped between the contact lens and the surface of the cornea these changes did not occur. The epithelial cells must respire to remain healthy and to keep the ionic balance normal in the corneal stroma.

Vascularization of the cornea of the rat occurs when there is deficiency of many separate amino acids, vitamin A or riboflavin. In man vascularization occurs in riboflavin deficiency. Riboflavin is present in corneal epithelium as flavinadenine dinucleotide and presumably functions as a link in metabolic oxidations. The oxygen uptake of the epithelium and the riboflavin content of the cornea are depressed before vascularization begins (Lee & Hart, 1944; Bessey & Lowry, 1944). A noticeable feature of the riboflavin-deficient rat is that the eyes sink deep into the head. This effect is due to the degeneration of the lacrimal glands rather than to failure of

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