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COMMUNICATIONS

THE CLINICAL SIGNIFICANCE OF THE
OCULAR MUSCULATURE

With special reference to the intra-ocular pressure and the
circulation of the intra-ocular fluid

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IN the course of experimental investigations which we have been pursuing for some time, there has come to light a series of facts relating to the influence of the ocular musculature upon the physiology of the eye, which it may be of value to correlate, inasmuch as they have some clinical value. The observations refer to two main subjects: the circulation of the intra-ocular fluid, and the maintenance and variation of the intra-ocular pressure. With regard to the first, it has been suggested by one of us that the intra-ocular fluid is a dialysate of the capillary blood maintained in circulation by changes in pressure continually occurring in the eye: we would suggest that the evidence presented in this paper goes a considerable way to substantiate this theory. With regard to the second question, we do not think that sufficient attention has hitherto been devoted in the literature to the effect of the activity of the extra- and intra-ocular musculature upon the pressure of the eye. We shall also allude to some matters of clinical importance which follow directly from these questions, such as the action of

miotics and mydriatics, the diurnal pressure curve in glaucoma, the necessity for adequate akinesia in intra-ocular operations, and so on.

The Extra-ocular Muscles

We shall first consider the effect of the extra-ocular muscles upon the intra-ocular pressure. We shall deal with them seriatim: the muscles of the lids, the voluntary muscles of the eyeball, and the involuntary orbital muscle of Müller.

1. *The Lid Muscles.*—In these experiments dogs were employed, anaesthetized with ether-chloralose, and the intra-ocular pressure was recorded by the optical manometer described in a recent paper (1931).

Closure of the lids involves two completely distinct actions, an involuntary light pressure such as occurs in the action of blinking and involves the activity of the palpebral portion of the orbicularis alone, and a voluntary forced closure which involves a contraction of the orbital portion of this muscle in addition. The effect of the first of these actions upon the tension of the eye was studied in the dog by touching the cornea lightly with a hair in order to elicit the corneal reflex. Fig. 1 shows that even this light closure raises the intra-ocular pressure by 5 mm. Hg. The effect of the second action was studied by stimulating the facial nerve electrically after its exit from the stylo-mastoid foramen; this throws the whole of the orbicularis into contraction, and the subsequent rise of 26 mm. Hg in the pressure of the eye is seen in Fig. 2.

2. *The Muscles of the Globe.*—It is already well known that a contraction of the recti and obliques raises the intra-ocular pressure

FIG. 1.

The effect of blinking on the intra-ocular pressure. The blink was excited by touching the cornea of a lightly anaesthetized dog with a hair.

by compressing the globe: thus tonometric observations have shown that the tension of the eye rises on convergence. It is not generally recognized, however, that the normal tone of these muscles is responsible for the maintenance of almost one-half of

FIG. 2.

The effect of forcible closure of the lids on the intra-ocular pressure. The closure was excited by stimulating the facial nerve of a dog.

FIG. 3.

The effect of paralysis of the recti muscles on the intra-ocular pressure. 2 c.c. of 2 per cent. curare injected into the circulation of the perfused dog. The upper curve is the blood pressure, the lower the intra-ocular pressure. The displacement of the base line of the latter indicates a movement of the eye of exophthalmos owing to the muscular relaxation.

the normal intra-ocular pressure, a fact which is readily shown by the effects of curare. When this drug is administered a profound fall of intra-ocular pressure results which is due to a considerable extent to the coincident fall in blood pressure. If, however, an injection of curare is given while the blood pressure is maintained at a constant level by the technique of the perfused eye (Duke-Elder, 1931) the effects of the muscular relaxation can be observed uncomplicated by the influence of the general circulation. Fig. 3

FIG. 4.

The effect of a contraction of the extra-ocular muscles on the intra-ocular pressure. 1 c.c. 1 in 20 choline chloride injected intravenously into a dog. The upper curve is the blood pressure (B.P.), the middle curve a tracing of the superior rectus muscle (M), and the lower curve the intra-ocular pressure. The movement of the base line of the latter denotes a movement of the eye of enophthalmos, due to muscular contraction.

shows the result obtained in these conditions, which makes it clear that the pressure of the eye falls to almost half its original level.

A contraction of these muscles has the opposite effect. In a previous publication (Duke-Elder, 1930) it has been shown that choline or acetyl-choline when injected into the blood stream produces a contraction of all the recti. Fig. 4 shows the reaction to an intravenous injection of choline in the intact dog, when, of course, the

FIG. 5.

The effect of the injection of choline upon the perfused dog. 1 c.c. of 1 in 20 choline chloride injected into the circulation. The upper curve is the blood pressure (B.P.), the lower the intra-ocular pressure (I.O.P.) The movement of the base line of the latter denotes an enophthalmos.

rise of intra-ocular pressure is partly due to a coincident rise in blood pressure: while Fig. 5 shows the effect of the muscles alone in the perfused animal. In this connection the effect of eserine used in large doses is interesting. Fig. 6 shows the effect of an intravenous injection of 2 c.c. of a 1.0 per cent. solution of this drug in the perfused animal, and it illustrates the marked influence which results from the increase in the tone of the muscles as well as the effects of their fibrillary contraction.

3. *The Muscle of Müller.*—Contraction of the muscle of Müller by stimulation of the sympathetic cannot be studied uncomplicated by coincident vascular effects, since the vaso-motor nerves to the eye are contained in the same trunk; but if an animal is exsanguinated by opening the carotid, and then the sympathetic immediately stimulated, a rise of pressure is obtained which is due only to the

action of this muscle (Fig. 7). The reverse effect of a lowering of the intra-ocular pressure on a decrease in the tone of the plain muscle is seen after the administration of atropine (Fig. 8). The

FIG. 6.

The effect of large doses of eserine on the intra-ocular pressure in the perfused dog. With the injection of doses of the sizes of 2 c.c. of a 1 per cent. solution the muscular effect predominates. The sharp kink in the base line denotes an enophthalmos.

FIG. 7.

The effect of contraction of the plain muscle of the orbit on the intra-ocular pressure of the dog. Müller's muscle was made to contract by stimulating the cervical sympathetic in the newly exsanguinated animal.

FIG. 8.

The effect of atropine on the intra-ocular pressure of the intact dog. 0.4 c.c. 1 per cent. atropine injected intra-venously. The fall in the intra-ocular pressure is produced by a relaxation of the tone of the plain muscle of the orbit.

FIG. 9.

The effect of atropine (0.3 c.c. of a 1 per cent. solution) on the intra-ocular pressure of the perfused dog. The initial fall is due to relaxation of the tone of the orbital muscle; the subsequent small rise is due to a capillary dilatation caused by the atropine.

muscular effect here is complicated, for a coincident capillary dilatation due to the action of atropine on the blood vessels of the eye (Duke-Elder, 1931) produces a rise in intra-ocular pressure.

FIG. 10.

The effect of nicotine on the intra-ocular pressure of the intact dog. 1 c.c. of 1 per cent. nicotine injected intra-venously. The upper curve (B.P.) is the blood pressure; the lower curve (M) a tracing of the superior rectus, and the inset (I.O.P.) the intra-ocular pressure.

This rise comes on somewhat later than the fall due to muscular relaxation and the two effects can be readily analysed in the more efficiently controlled circumstances of artificial perfusion (Fig. 9).

Finally, the action of nicotine is interesting. The immediate effect of the action of this drug is to stimulate both the voluntary

and involuntary muscles of the orbit (Duke-Elder, 1931). Fig. 10 shows the very acute rise of intra-ocular pressure which follows its intravenous injection in the normal dog, a rise which is due partly to the contraction of the plain muscle (seen in the long and slow downward variation of the muscle tracing) and partly to the

FIG. 11.

The effect of 1 c.c. 1 per cent. nicotine on the perfused dog. The total effect is due to the contraction of the recti muscles.

coincident rise of blood pressure which follows the general sympathetic stimulation. Fig. 11 shows the extent of rise which is due to the action of the muscles alone when the blood pressure is kept constant in the perfused animal.

The Intra-ocular Muscles

The fact that the ciliary muscle on contraction pulls on the scleral spur and thereby opens out the canal of Schlemm and the trabeculae of the angle of the anterior chamber, is already well known. I have recently had the good fortune to receive from Dr. Fortin, of Buenos Aires, a series of microphotographs which show this action more clearly than I have seen elsewhere. Fig. 12 shows the arrangement of the structures at the angle of the anterior chamber in an eye enucleated one hour after death and rapidly

fixed; and Fig. 13 is taken from a section of an eye which was under the action of eserine at the time of death. The pull of the ciliary muscle on the scleral spur and the widening of the spaces between the trabeculae is very obvious. Fig. 14 forms an interesting comparison: it is taken from a glaucomatous eye, and demonstrates how the apposition of the iris to the cornea and the general

FIG. 12.

The normal angle of the anterior chamber in a rapidly fixed eye (Fortin). S. Canal of Schlemm. C.A. Anterior chamber.

configuration of the entire region of the drainage angles makes free filtration impossible.

A further point, too, emerged from Dr. Fortin's beautiful histological researches. It appears that the ciliary arteries as they run forwards traverse the substance of the ciliary muscle, the fibres of which encircle them as a sphincter: one such arterial branch is demonstrated in Fig. 15. It follows that the arteries supplying the anterior part of the eye are compressed on contraction of this muscle, so that the blood flow will be lessened. At the same time the traction of the fibres on the choroid will tend to open out the veins of this tissue so that, in addition to diminishing the arterial supply, the venous return is aided in the same way as the exit of fluid is assisted through the canal of Schlemm.

FIG. 13.

The angle of the anterior chamber in an eye under the influence of eserine (Fortin).

FIG. 14.

The angle of the anterior chamber in a glaucomatous eye (Fortin).
S. Canal of Schlemm. A. Angle of anterior chamber.

FIG. 15.

Micro-photograph of the ciliary muscle.

The Pressure Circulation of the Intra-ocular Fluid

The hydrostatics of the drainage of the intra-ocular fluids can be deduced from a study of the venous pressure of the eye (Duke-Elder, 1926), the mechanism of which is made clear from Fig. 16. When the intra-ocular pressure is at its normal level (say 20 mm. Hg, Fig. 16A) the pressure in the veins inside the eye is 2 mm. Hg above this (22 mm. Hg), and that in the veins traversing the sclera is about 1 mm. Hg above (21 mm. Hg). The canal of Schlemm is a direct off-shoot of the intra-scleral veins and its contents also will be at the same pressure. When, however, the intra-ocular pressure is raised above its normal level (say to 23 mm. Hg) (B, Fig. 16), the chamber pressure of the eye constricts the exit veins and the circulation proceeds when the pressure in the veins just about to enter

FIG. 16

the sclera is a fraction above this level (23 + mm. Hg). Lying further down the venous stream, the pressure in the intra-scleral veins (and in the canal of Schlemm) is found to be about 1 mm. Hg below the intra-ocular pressure, so that fluid can drain through the trabeculae of the angle of the anterior chamber directly into it. We have seen in a previous publication (Duke-Elder, 1931) that every pulse beat and respiratory excursion raises the intra-ocular pressure to a sufficient height to establish such a pressure circulation. It is true that in the human subject the action of the plain orbital muscle can almost be discounted; but when we remember that all through the waking hours there is a regular rhythm of blinking movements occurring every few seconds as well as constant activity of the recti and obliques, it would seem that there is ample cause for the establishment of an efficient pressure circulation. To this, of course, must be added the activity of the ciliary muscle, which, by opening up the trabeculae of the angle of the iris, makes drainage easier, by widening the canal of Schlemm aids the hydrostatic out-flow by suction, by compressing the ciliary arteries lowers the blood pressure, and by opening up the choroidal veins creates a low pressure in them, again aiding the absorption and elimination of fluid.

A word with regard to the action of mydriatics and miotics. Apart from their already well-recognized action in mechanically blocking and freeing the angle of the anterior chamber, atropine, by releasing all pressure on the arteries supplying the anterior uvea, tract and allowing the veins of the anterior part of the choroid to collapse, will tend to produce a condition of circulatory stasis and hyperaemia; eserine, on the other hand, by constricting the arteries and opening up the veins, will restrict the inflow and aid the outflow of blood, as well as accelerating the outflow of fluid through the drainage angle. The former will thus tend to raise the intra-ocular pressure, the latter to lower it.

The *diurnal pressure curve* in the normal eye is already a well-known physiological phenomenon. The pressure varies throughout the day by some 2 to 3 mm. Hg as is seen in Fig. 17; it is highest

FIG. 17.

The diurnal variation of the intra-ocular pressure of a normal adult man, taken tonometrically.

in the early morning before the subject commences the day's activities; after getting up it falls, at first rapidly and then more slowly, until the evening when the subject retires to rest. Through the night in bed the reverse phenomenon occurs: a rise occurs, again in two stages—a slow and gradual rise during the first few hours, and then a more rapid rise in the early morning. This is almost certainly due to the influence of the pressure-circulation: the absence of muscular activity during the night allows the pressure to rise, and the commencement of movements in the morning immediately lowers it. It is significant that in most cases of chronic glaucoma the diurnal variation is very much exaggerated; and in case of doubtfully raised tension it is a wise procedure to take the tension of the eye while the patient is still in bed and before the activities of the day are commenced.

Operative Akinesia.—The enormous influence of the extra-ocular muscles on the intra-ocular pressure demonstrates the necessity for adequate akinesia in all intra-ocular operations. When it is remembered that a relatively mild contraction of the orbicularis raises the intra-ocular pressure from 27 to 53 mm. Hg, the danger of loss of vitreous in a cataract extraction is obvious unless this muscle is thrown out of action. It follows that in all such operations the orbicularis should be paralysed, either by injection of the facial nerve as it crosses the ramus of the mandible or by a local injection around the orbit: the former method is the prettier, the latter the easier and more certain. Further, the action of looking down raises the pressure of the eye by the contraction of the recti, a rise which becomes quite marked if the action is forced. If every precaution is to be taken, a retro-bulbar injection of novocaine should be employed. This should be employed as a very dilute (0·25 or 0·5 per cent.) solution injected immediately before commencing the operation so that the muscles are not wholly paralysed but merely weakened, allowing the patient to look down but not to do so forcibly; or alternatively, a stitch should be inserted into the superior rectus so that the eye can be adequately controlled. Such a procedure incidentally infiltrates the ciliary ganglion thus rendering the inner eye completely anaesthetic, and results in a degree of immobility and control which has to be seen to be believed.

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NOTE.—Blocks for illustrations, Fig. Nos. 1, 2, 3, 4, 7, 9, 10 and 17, kindly lent by Henry Kimpton.

SIR WILLIAM READ'S TREATISE OF THE EYES

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ACCORDING to Hirschberg, Sir William Read published a "Treatise of the eyes containing a short, but exact, description of the structure, situation . . . as also causes, symptoms and cures of 130 diseases incident to them," London, 1706. This information, he states, is obtained from the *Biog. Lexicon*, Vol. IV, 683; Haller, *Bib. chir.*, 1,574, only gives the short title "Diseases of the Eye, 1706," taken over by Beer, *Rep.*, Vol. I, 12. Neither Haller nor Beer seems to