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Studies on the Etiology of Glaucoma Part 4. On the Effector Organs in Eyeball

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Abstract

From these experimental results, the author has reached the following conclusion: The choroid possesses abundant blood vessels, and inasmuch as they carry a large amount of blood on account of their large tubular space, they also have such structural formation as to enable their distension or contraction greatly to influence the volume of intraocular contents. Moreover, as the autonomic nerves distributed in the eye are connected with the wall of vessels in a compact network of nerve fibers, the width of the choroidal vessel can be regulated by the autonomic center ; and thus the intraocular pressure seems to be regulated by an increase or a decrease in the amount of intraocular circulating blood. On the other hand, the ciliary body likewise seems to take a part in the adjustment of the eyepressure as the width of vessels, the permeability of blood vessel walls, and the aqueous production are all controlled by the autonomic nerve, and because the contraction of ciliary muscles, as already mentioned, also exerts a great influence on the intraocular pressure. Therefore, the author believes that a regional adjustment of eye pressure is being performed by these mechanisms, working as they are in conjunction with each other, and maintaining a harmonious relation among themselves under the control of the autonomic center.

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STUDIES ON THE ETIOLOGY OF GLAUCOMA

PART 4. ON THE EFFECTOR ORGANS IN EYEBALL

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The fact that the normal intraocular pressure is always kept within narrow limits of variation is well known. As reported in the previous publications, the author believes that stability of this eye pressure, like other important functions such as heart beats, blood pressure, pupillary activity, body temperature, and intestinal motility, is maintained by an autonomic reflex, and that its reflex center is located in the diencephalon, having for its afferent tract the ophthalmic nerve and for its efferent tract some autonomic nerves. Moreover, he holds a belief that in case of abnormal changes in the intraocular pressure, the stimuli by these changes are relayed to the adjustment center of the eye pressure located in the diencephalon by way of the ophthalmic nerve, thus exciting the center, and that the impulses being imparted from the excited center are transmitted to the eyeball mainly by the autonomic nerve, subsequently causing various changes within the eyeball, and thereby the eye pressure is always properly adjusted. However, little is known as regards exactly to what part within the eyeball the impulse from the eye-pressure center is transmitted and what changes the impulse might bring about within the eyeball. Of many regional factors that exert influences on the eye pressure, some of the most important ones are as follows:

i. The amount of intraocular contents: namely, the amount of blood in the intraocular vessels and aqueous humor, and the volume of lens crystalline, vitreous, uvea and retina.

ii. Elasticity of the eyeball wall.

Of these, the most variable and most influential on the eye pressure are blood circulation and aqueous humor in the eyeball, and in addition the two have an intimate correlation with each other.

An increase in the volume of intraocular fluid inflow causes a rise in the eye pressure; while a decrease in the volume of intraocular blood and aqueous humor, and an increase in the rate of aqueous outflow

bring about a decrease in the eye pressure. Therefore, it is natural to think that the state of intraocular blood vessels has an extremely great bearing on a rise or a fall of the eye pressure.

ELWYN¹ has picked the following three units as the effector organs for the maintenance of normal intraocular eye pressure :

- (1) The capillary walls and walls of SCHLEMM's canal.
- (2) The amount of circulating aqueous humor.
- (3) The amount of circulating blood.

The investigators upholding the neurovascular theory, of them, DUKE-ELDER being the representative, have pointed out vascular disturbances within the eye as the cause of glaucoma.

OBSERVATIONS

As is clear from these, since the blood vessel system in the eye seems to have a very close relationship with eye pressure, the author has first investigated the blood vessels in the eye, uveal vessels in particular.

1. Distribution of uveal vessels².

The eyeball of the rabbit previously injected intravascularly with indian ink had been enucleated and made transparent using xylol or winter green oil, after fixing with formol and a study on the distribution of blood vessels in the eye was carried out.

Of the results, the most interesting finding is the distribution of choroidal vessels. Namely, choroidal vessels are found quite abundantly, and especially their veins are numerous and their tubular spaces much larger and their anastomoses more numerous than those of arteries. In addition, their capillary spaces are big, presenting the form that looks like a sinus as well as close-knitted meshes (Fig. 1).

The finding especially noteworthy is the relation of positions between the vascular layer and the capillary layer; i. e. the two are not located on the same plane but they are joined by the junctions branching out at right angle. Such a structure of the distribution resembles that of the liver and pancreas; and moreover, it is convenient for the passive retention of blood as well as suitable for the adjustment of the influences of systemic blood pressure, alleviating as much as possible these influences, acting as it does as a sort of buffer. In other words, choroidal vessels minimize the influences of systemic blood pressure as best they can, and also they have distribution structures which enable them to facilitate the regulation of the amount of blood circulating in the vessels. Both the



Fig. 1 Choroidal vessels

afferent and the efferent vessels of ciliary vessels are quite slender but the capillaries in between the two have markedly big tubular spaces as well as abundant anastomoses. As the rate of blood flow at this area is quite slow, ciliary vessels seem, virtue of its very structure, to be well suited for the circulating substances to permeate (Fig. 2). In contrast to



Fig. 2 Ciliary vessels

this, vessels of the iris are not suitable for blood retention or for the permeation of substances as both their tubular spaces and numbers are small, though their curvatures are pronounced.

From these findings, choroidal vessels seem to be able to adjust readily the amount of blood they carry, and moreover, they appear to regulate the eye pressure by virtue of their possessing a distribution

construction so convenient as to alleviate the influences of systemic blood pressure. On the other hand, ciliary vessels seem to possess a distribution construction suitable for the permeation of substances, and for that very reason, it seems that they adjust the eye pressure by controlling the production of aqueous humor.

2. Innervation in the uvea³.

Of the workers who have investigated neural regulators of the intraocular pressure, there are LAUBER⁴, SCHALY and LÖWENSTEIN⁵. LAUBER⁴ states that he finds a ganglion cell group in the ciliary body, which, he believes, is likely to be a "sensitive pressure-receptor" like sinus caroticus, and which by sensing the pressure and transmitting it to the center by way of the sympathetic nerve, regulates the eye pressure by reflexes.

SCHALY claims that pericyte, which is found in arterioles before they are connected with capillaries, also exists in the eye, and it is this pericyte that regulates the amount of blood in uveal vessels by controlling the size of capillary space. LÖWENSTEIN⁵ reports that he finds a big, round, polygonal cell group at the distal end of posterior choroidal artery, and he claims that this is a glomus cell group connected with sympathetic nerve, possessing functions to regulate the openings at the arteriovenous communication, and controlling the amount of intraocular blood. To this report, ORBÁN⁶ and KISE⁷ agree, while ASHTON refuses it by saying that he has been unable to find such a cell group.

The author has traced the routes of nerve fibers by staining the uvea of the albino rabbit with GROSS-SCHILTZE's, and KULTZCKY's stainings, and has investigated the relationship between the routes and vessels, reaching the following results :

The innervation in the choroid is quite abundant ; and especially around its arterial branches, a dense and abundant nerve plexus is found ; and at the distal end of its nerve fibers, STOER's so-called "Terminal Reticulum" is formed and their ends are connected with the muscle fibers of arterial vessel walls (Fig. 3).

The innervation of venous branches is relatively less abundant but the nerves are likewise connected around these branches in a network form with occasional "terminal Reticulum". In the ciliary body and iris, the innervation for main blood vessels is not quite so compact but show a simple communication of nerve fibers ; and no "Terminal Reticulum" can be found. At the roots of the ciliary processes, however, a network of nerve fibers is formed, and this network seems to possess neural functions to control the aqueous production. Moreover, occasional ganglion cells can



Fig. 3 Innervation in choroid

be recognized in the choroid.

From these experimental findings the following assumption may be made :

Those autonomic nerves entering into the choroid are mainly attached around arterial branches, and they perform the neural control over the rate of circulation and over the amount of blood ; and in addition some are connected around venous branches, performing likewise a neural control. In the ciliary body, however, the autonomic nerve seems more likely to play a regulating rôle on the aqueous production, consequently adjusting the intraocular pressure. The choroidal veins also seem to play an important rôle in the adjustment of the eye pressure by their passive dilatation and contraction.

3. Functions of the ciliary muscles⁹.

There are two or three investigators who support the opinion that the ciliary muscles, involved as they are in the outflow of aqueous humor, play a rôle in the adjustment of the intraocular pressure. FORTIN¹⁰ reports that on the contraction of ciliary muscles the dilatations of FONTANA's spaces and SCHLEMM's canals occur, thus inducing simultaneously the compression of the posterior ciliary arteries and the dilatation of the anterior ciliary veins, which, in turn accelerating the aqueous outflow, bring about a decrease in the intraocular pressure. STIEVE¹¹ mentions that as the posterior parts of meridional fibers in ciliary muscles are attached to the collagen and the elastic fibres in the choroid, the contraction of the ciliary muscles regulates the amount of choroidal blood. THIEL¹² also states that the meridional fibers mentioned above possess

the function to regulate the amount of blood outflow from the eyeball through vortex veins.

The author this time, by using normal human eye with its pigment decolorized, studied the anatomical relation of ciliary muscles with other parts, and it has been demonstrated that the anterior ends of meridional fibers of the ciliary muscles are connected with scleral spur while their posterior ends reach both the elastic and the collagen fibers of choroid (Fig. 4). These findings seem to suggest that the contraction of ciliary



Fig. 4 Anatomical relation of ciliary muscles with SCHLEMM's canal

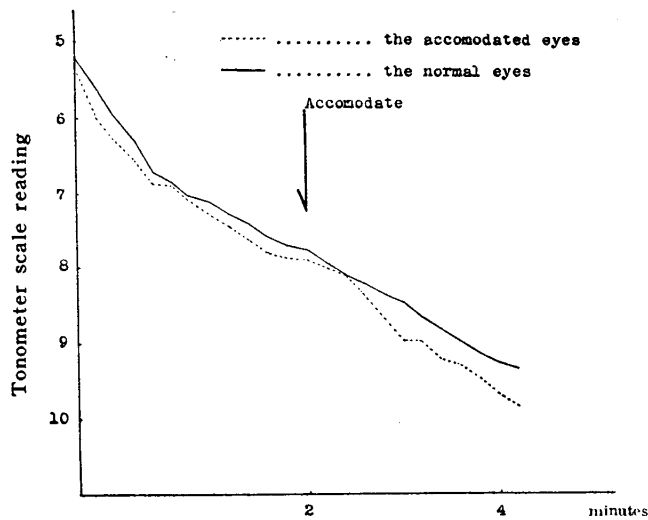


Fig. 5 Tonographic tracing of the accommodated eyes.

muscles brings about a decrease in the intraocular pressure by accelerating the aqueous outflow as well as by forcing blood out of choroid. In fact, the author has been able to confirm, by the tonography that the accommodation actually accelerates the aqueous outflow (Fig. 5).

CONCLUSION

From these experimental results, the author has reached the following conclusion :

The choroid possesses abundant blood vessels, and inasmuch as they carry a large amount of blood on account of their large tubular space, they also have such structural formation as to enable their distension or contraction greatly to influence the volume of intraocular contents. Moreover, as the autonomic nerves distributed in the eye are connected with the wall of vessels in a compact network of nerve fibers, the width of the choroidal vessel can be regulated by the autonomic center ; and thus the intraocular pressure seems to be regulated by an increase or a decrease in the amount of intraocular circulating blood. On the other hand, the ciliary body likewise seems to take a part in the adjustment of the eye-pressure as the width of vessels, the permeability of blood vessel walls, and the aqueous production are all controlled by the autonomic nerve, and because the contraction of ciliary muscles, as already mentioned, also exerts a great influence on the intraocular pressure.

Therefore, the author believes that a regional adjustment of eye pressure is being performed by these mechanisms, working as they are in conjunction with each other, and maintaining a harmonious relation among themselves under the control of the autonomic center.

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