THE ARTERIAL PRESSURE IN THE EYE.

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ALTHOUGH several observers have claimed to have measured the arterial pressure in the eye, no one has yet succeeded in doing so. With one exception all the methods of technique hitherto adopted depend on raising the intra-ocular pressure and simultaneously noting the behaviour of the arteries. The eye thus acts as a sphygmomanometer; marked pulsation of the arteries is taken as the diastolic pressure, and their complete obliteration as the systolic. Since, however, the column of blood in the central artery of the retina and in the ciliary arteries is immobilised by this procedure, the pressure obtained is not that of the intra-ocular arteries, but the lateral pressure at the most proximal branching of the feeding vessel—the ophthalmic artery.

The intra-ocular pressure has been raised by two methods:

1. By inserting a manometer into the eye, and raising the pressure therein. The points of maximum pulsation and cessation of pulsation have been estimated either as observed ophthalmoscopically in the retinal artery (Schoeler (1) mean pr.—70 mm. Hg; v. Schultén, (2) Diastolic/Systolic pr.—90–120/100–130 mm. Hg: rabbit), or by measuring the amplitude of the pulsations communicated by the arteries to the mercury column in the manometer (Weiss (3), D./S. pr.—50–70/80–110 mm. Hg; Wessely (4) D. pr.—70 mm. Hg: rabbit)[1].

2. By raising the tension of the intact globe by the application of external pressure, either by applying to the eye an air-filled pressure chamber connected with a manometer and provided with a transparent window through which the retinal circulation can be observed (Bleidung (5), D./S. pr.—64–75/96–117 mm. Hg in man), or by a piston working against a standardised spring ("dynamometer"), the ocular tension at the time of appearance and disappearance of the retinal pulse being estimated by a tonometer (Bailliart (6)). This latter procedure has been used extensively clinically, and the results of different observers vary by over 100 p.c., being much lower on the whole than those derived from the former method; Bailliart gives—D./S. pr.—25–30/50–70 mm. Hg in man. Apart from the limited value of the tonometric method of recording pressures in

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[1] Lullies and Gulkowitsch (*Schriften d. Königsberger gelerhrten Ges.* Bd. 2, H. 2, 1924) appear to have followed a similar procedure. I have been unable to gain access to the original paper; but, from an abstract, their results would seem to be D./S. pr.—54–70/92–108 mm. Hg: rabbit.

any other than a comparative sense, the eye, rendered tense by this procedure, is pressed back into the orbit, thus kinking and compressing the vessels behind it. This doubtless accounts for the lowness of the results obtained. In laboratory animals Bailliart's results are higher (D./S. pr.—40/100 mm. Hg: cat). The discrepancy is probably explained, not on any normal pressure difference in the retinal arteries of the two, as Bailliart claims, but by the fact that these animals have two ophthalmic arteries, one derived from the external and one from the internal carotid, which anastomose so freely that on the obliteration of one or other of them the intra-ocular circulation can be maintained. Whatever doubtful clinical value these results may be construed to have, considered merely as figures with a comparative and no absolute significance, they are no record of the retinal arterial pressure, and are valueless even as an index of the pressure in the ophthalmic artery or of the relation between the intra-ocular pressure and the vascular pressures in the eye.

The pressure in the anterior ciliary arteries in man, as they are seen under the conjunctiva just before they enter the eye, has been measured by Seidel (7) and Hiroishi (8) by applying a pressure chamber connected with a manometer over them. D./S. pr. appeared as 30–45/55–75 mm. Hg. Seidel assumed that the pressure of the arteries in the eye, particularly those in the ciliary body which govern the formation of aqueous, was necessarily less than this. But these vessels at their entrance into the eye are very minute and have undergone several sub-branchings since leaving the ophthalmic artery; their pressure will therefore be presumably less than that of the central artery of the retina and the posterior ciliary arteries which enter the eye directly from this parent vessel. Moreover there is a considerable amount of physiological evidence that the small anterior vessels play a subsidiary part in the maintenance of the ocular circulation. In some animals they are absent, and when they are present no markedly deleterious effects result from their obliteration, while section of the posterior ciliaries, two of which run without subdivision up to the region of the ciliary body, is followed by complete hypotony and widespread degenerative changes even involving structures as anteriorly situated as the cornea.

1. *The arterial pressure in the eye.* The arterial pressure in the branches of the retinal artery was measured by a micro-injection method carried out by the introduction into their lumen of a micro-pipette of the type described by Barber (9), its movements being controlled by a micro-manipulator[1] modified from that elaborated by Chambers (10). The animals employed were cats. It was seen in a previous paper (11) that for the measurement of the venous pressure of the eye, dogs were the most suitable; but in these animals the retinal vessels are ensheathed and partially obscured by neuroglia, only fine branches being visible on the optic disc. The retina of the cat most nearly resembles that of man, and in it (usually three) comparatively large arteries, each flanked by a vein, are readily seen.

Anæsthesia was induced by ether, and maintained by intravenous chloralose. The lower lid was reflected along with the soft tissues, the periosteum elevated, a V-shaped piece of bone removed from the lower

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[1] This was made at the suggestion of Prof. Leonard Hill by Dr Schuster at the National Institute for Medical Research.

orbital margin, and the under-surface of the globe of the eye exposed. The animal's head was then securely clamped (*A*, Fig. 1) in a suitable position. A hollow needle (*B*) of large bore to prevent any valvular action, and provided with a side-arm, was inserted into the vitreous, and connected to a compensated mercury manometer (*C*) and saline reservoir (*C′*) by means of a capillary tube containing an air bubble to serve as an index of equilibrium. The side-arm of the needle was connected with a second reservoir filled with physiological saline (*D*). The normal intra-ocular pressure was taken in the usual way by means of the compensated manometer; the reservoir (*D*) was then raised to a corresponding height and its connection with the eye opened—by this means the intra-ocular pressure was kept at its normal level throughout all the subsequent experimental manipulations. A self-illuminating ophthalmoscope (*E*) was then adjusted to obtain a good view of the fundus by the direct method, and was clamped into position. The sclerotic was then pierced well behind the equator of the eye by a fine

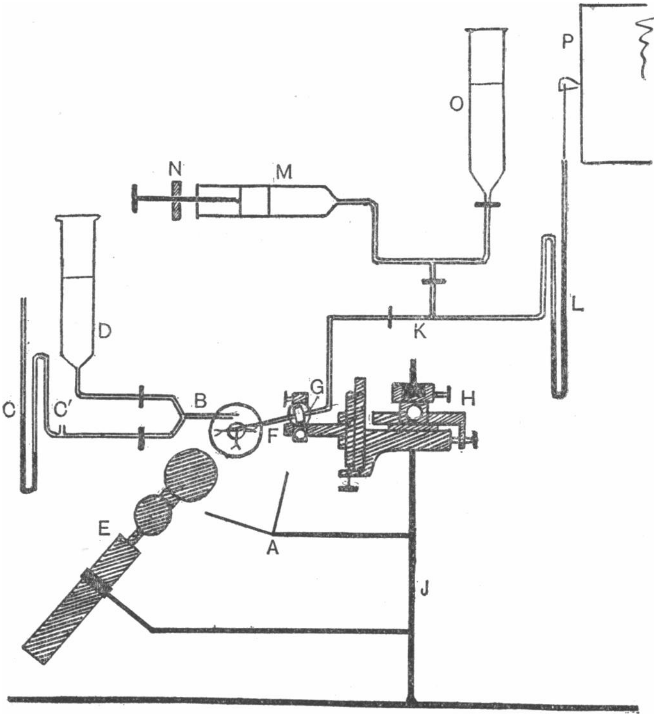

Fig. 1. Pressure in intra-ocular arteries.

metal needle, and the micro-pipette (*F*), carrying a collar (*G*), was inserted immediately on the withdrawal of the needle into the back of the globe through the hole thus made. The pipette was made by drawing out a glass capillary tube over a micro-burner into a needle with a rapidly tapering tip, and converting this into a pipette by jamming its point against a cover-glass until it broke off with a tip of such a size as would enter the branches of the retinal artery (about 0·1 mm. diam. at the disc), and when it was in place would allow the circulation therein to proceed unimpeded. Under the guidance of the ophthalmoscope, the tip was made to approximate closely to the branch of the artery on the side of the disc opposite to that at which the pipette was inserted, and when in this position, the micro-manipulator (*H*) was brought into position, and the collar securely fixed by a screw. The manipulator, the animal's head, and the ophthalmoscope were all clamped to the same support (*J*) in order to secure rigidity of adjustment. The manipulator was provided with a system of adjusting devices, governed by screws opposed by springs, so that the movements of the tip of the pipette could be accurately and continuously controlled in any direction, and maintained securely in any desired position. Under observation through the ophthalmoscope the tip was thus made to enter the lumen of the artery by adjusting the screws on the manipulator. The micro-pipette was connected by tubing (*K*) to a mercury manometer (*L*), the whole system being filled with a solution of methylene blue in physiological saline. Any desired pressure was made to act upon the pipette tip by means of a syringe (*M*) whose movements were accurately controlled by a milled screw adjustment (*N*) on the piston, while a constant supply of solution was maintained by recharging the syringe from a reservoir (*O*) and suitably adjusting the stop-cocks.

While the pipette was being manipulated into the artery, the system was kept at the normal intra-ocular pressure so that none of the methylene blue escaped into the eye and obscured the field. Once it was introduced, blood was seen to flow up into it. The pressure was then raised until the methylene blue solution flowed continuously into the artery—this was easily seen ophthalmoscopically. The pressure was then lowered until a slight stoppage of this flow occurred at systole, when a little blood tended to enter the tip of the pipette. On lowering the pressure further the dye and the blood fluctuated in the tube, and no flow took place, until a point was reached when an almost steady flow of blood into the pipette occurred with a periodic stoppage at diastole, when a small spurt of the dye entered the vessel. These two pressures were recorded by marking their height on the kymograph (*P*), a correction factor being added to allow for the influence of a column of saline equal to the differences in level between the manometer and the eye.

Several series of readings were taken in each experiment, the mean of which are given in Table I.

TABLE I.

No. of cat	Intra-ocular pressure mm. Hg	Pressure retinal arteries mm. Hg		
		Systolic	Diastolic	Mean pressure interpreted as $\frac{S+D}{2}$
1	22	91	65	78
2	25	88	59	73·5
3	29	94	69	81·5
4	20	86	65	75·5
5	23	83	63	73
Average	24	88·5	64	76

2. *The pressure in the ophthalmic artery.* The pressure in the ophthalmic artery was measured by a method modified from that adopted by previous workers by making use of the eye as a natural sphygmomanometer. In the criticism of their results it was seen that any interference with the circulation behind the globe by pressure applied to the intact eye entirely vitiated the results, and therefore a manometric method of raising the pressure was adopted. The pulse was both observed by the ophthalmoscope and recorded by the oscillatory method. The pressure pulse of the arteries is communicated by the incompressible contents of the eye to the elastic sclerotic as a volume pulse. This pulse is due to the intra-ocular arteries, and is not communicated from the orbital vessels, since, on inducing local endocular hyperæmia (by subconjunctival saline injections, etc., Wessely(4)) the ocular pulse increases proportionately, while a simultaneous carotid tracing shows no change. Inasmuch as the chorioidal vessels form 8/10 of the entire circulation of the eye, the pulse will be largely due to their influence, which is demonstrated by the fact that clinically, in cases of embolism of the retinal artery, when this vessel is occluded, the pulsations of the eyeball, as shown by the lever of a tonometer, proceed as usual. The pressure in the ophthalmic artery is thus measured through the central artery of the retina by the ophthalmoscopic method, through the posterior ciliary arteries by the oscillatory one.

In the first method it was found to be very difficult to observe the retinal circulation sufficiently exactly to get accurate end-points.

V. Schulten inserted the manometer into the vitreous, but here the difficulty of blocking the point of the needle by valve action complicates accurate readings when the pressure is made to vary. When the needle is immersed in the aqueous, the corneal astigmatism brought about by its insertion tends to blur the view of the fundus, an effect which is increased by the raised pressure tending to displace and alter the dioptric properties of the lens. The end-points, moreover, are not sharp. In the previous series of experiments it was easy to differentiate between the methylene blue and the red blood; but here, while arterial pulsation was seen to increase until pressures of 70 to 90 mm. Hg were reached, it was very difficult to say with certainty where the maximum occurred. Similarly, at 110 to 120 mm. Hg the blood flow in the vessels was seen to stop, and at pressures 5 to 10 mm. Hg above this the vessels usually to a greater or less degree became collapsed and flattened out; but here again the end-point is indefinite, and does not lend itself to objective exactitude.

Reliance was therefore placed more upon the oscillatory method. Since the pulsation is communicated to the sclerotic, its magnitude has been estimated by the excursion of the lever of a tonometer placed upon the globe. But the distensibility of the coats of the eye (Koster(12)) decreases as its tension is raised, and the pulse is correspondingly damped; any method, therefore, which purports to compare the variations of the ocular pulse with increasing pressure by measuring its amplitude as communicated to the sclerotic is progressively more inaccurate as the tension rises. This error is overcome by opening the eye and putting its fluid contents in free communication with a rigid fluid system where the oscillations can be studied, conditions being so arranged that they are magnified to the greatest degree possible.

A manometer needle (*A*, Fig. 2) of large bore (1 mm.) to ensure free communication of the oscillations, and provided with a side-arm, was inserted through the cornea, the needle point being kept in the periphery of the anterior chamber to allow ophthalmoscopic examination of the fundus. From the side-arm a tube (*B*) was connected up with a compensated mercury manometer (*C*) with a reservoir (*C'*). The tube was connected with a syringe (*D*) whose piston was controlled by a screw adjustment (*E*), and the whole filled with saline, a constant supply of which was obtained from a reservoir (*F*). The straight end of the manometer led directly into a fine capillary tube (*G*) lying horizontally, on to which was attached a scale graduated arbitrarily. The capillary was connected by rubber tubing to a glass tube (*H*) containing saline, which acted as a reservoir and could be raised or lowered by a pulley. This reservoir was made as small as was convenient in order to reduce the inertia of the fluid column in the capillary (*G*), and make the oscillations as free as possible.

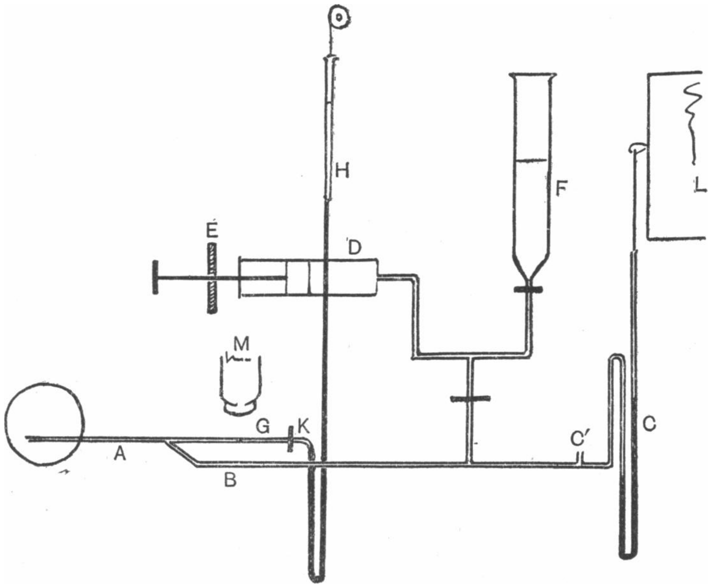

Fig. 2. Pressure in ophthalmic artery.

When the manometer was inserted, the reservoir (*H*) was shut off by a stop-cock (*K*); an air bubble was then introduced into the tube (*B*), and the pressure in the system adjusted by manipulating *C′* until the bubble was stationary, the normal intra-ocular pressure being thus recorded on the manometer. Communication with the reservoir (*C′*) was then closed and that with the reservoir (*H*) opened after its height had been adjusted to correspond with that registered by the manometer. The pressure in the syringe was then slightly increased while the level of the reservoir (*H*) was kept unaltered, so that the air bubble travelled slowly down the tube (*B*) and along the capillary (*G*). Having arrived here it was kept constantly in the same place by raising or lowering the reservoir coincidently with any subsequent manipulations of the syringe. When the pressure in the eye was varied by means of the syringe the behaviour of the retinal artery was observed ophthalmoscopically and the excursion of the air bubble in the capillary was noted through a microscope (*M*). The points of maximum oscillation and cessation of oscillation were marked on the kymograph (*L*), and were subsequently measured, corrections being applied to compensate for a column of saline equal to the difference in level between the eye and the manometer.

There follows the protocol of a typical experiment; the figures expressing the amount of oscillation refer to the divisions of the scale and are therefore arbitrary and of purely comparative significance.

TABLE II.

Cat Intra-ocular pressure mm. Hg	Ophthalmoscopic appearances	Amplitude of oscillation
26	Vessels normal; no pulsation	4–5
28	Venous pulsation at disc; arteries normal	4–5
40	Veins definitely engorged; arteries pulsating slightly	6–7
60	Veins begin to become constricted; arteries pulsating	8–10
70	Arterial pulsation increasing	11–12
75	„ „ „	14–15
78	Arteries pulsating maximally (?)	18–20
80	Arterial pulsation marked	16–17
90	„ „ less	9–12
110	Veins constricted; arteries filling at systole	6–7
120	Veins collapsed; arterial pulsation ceased	0
125	Arteries barely visible	0

Mean carotid pressure: 114 mm. Hg

Taking the point of maximal pulsation as the diastolic and that of cessation of pulsation as the systolic pressure, the results of a series of six experiments are given in Table III.

TABLE III.

		Pressure in ophthalmic artery: mm. Hg			
No. of cat	Intra-ocular pressure mm. Hg	Diastolic	Systolic	Mean pressure interpreted as $\frac{S.+D.}{2}$	Mean carotid pressure mm. Hg
1	26	78	120	99·5	108
2	29	85	129	107	118
3	26	74	106	90	96
4	23	81	110	95·5	100
5	25	73	116	94·5	108
6	20	80	109	94·5	104
Average	25	78·5	115	97	106

3. *The mean pressure as measured in the carotid artery* was registered by a mercury manometer. Only in one case (Table IV) were the four measurements taken in the same animal; as a general rule the length of time occupied by the manipulations and the consequent change in the animal's condition rendered comparative values of little account. If it be permitted to transpose the venous pressures in the eye of the dog

as determined in a previous paper (11), we get the following pressure relationships.

Table IV.

	mm. Hg		
	Systolic	Diastolic	Mean
Cat: Pressure as measured in carotid artery (right side)	—	—	105·5
Pressure in ophthalmic artery (right)	119	80	99·5
Pressure in retinal artery (left) *i.e.* in first arterial branchings in eye	86	65	75·5
Dog: Pressure in venous exits	—	—	21·5
Cat and dog: Intra-ocular pressure	—	—	20
Dog: Pressure in extra-ocular veins	—	—	12·2

It is seen that the pressure in the ophthalmic artery is only a few mm. Hg below that measured in the carotid[1], that is, below the aortic pressure, and that in the first branching inside the eye a larger fall of about 25 mm. Hg or almost 25 p.c. of the total pressure occurs. Between this and the veins a large fall of 54 mm. Hg takes place. This distribution of the pressure gradient is in conformity with that encountered in other parts of the body, where the arterial pressure is maintained at a fairly constant high level until the smaller arteries are reached.

The systolic pressure in the carotid was determined with the same technique as that employed in measuring the pressure in the retinal arteries by the insertion of a pipette. A mean pressure of 108 mm. Hg was found to correspond with a systolic maximum of 150 mm. The large amplitude of the pulse pressure and the impossibility of seeing the methylene blue solution entering this artery, however, rendered the method unsatisfactory for obtaining correct readings of the diastolic pressure: to obtain a satisfactory diastolic end-point the arterial wall must be so thin as to be transparent. For the same mean pressure it is probably about 70 mm. Hg.

Discussion.

From the physiological standpoint the main interest in these vascular pressures is their relation to the formation of the aqueous humour. This is associated mainly with the vessels in the ciliary body and the iris. From a theoretical point of view it would have been preferable to have obtained measurements of the arterial pressures here. In the cat the circulus arteriosus iridis major, which supplies the ciliary processes and iris directly, instead of lying inaccessibly at the base of the iris as in man, lies in the iris itself, and with sufficient magnification is readily seen particularly on the nasal side. To introduce a pipette into this

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[1] The pressure in the carotid artery was taken last: there is probably, therefore, an error, comparatively, due to a decline in the animal's condition.

vessel, however, was found to be very difficult or impossible on account of the mobility of the supporting structures, while the immediate and high rise in the intra-ocular tension which followed penetration of the iris—due presumably to vaso-motor reflexes from this highly innervated structure—seemed to render any such attempt useless. This vessel, however, is directly formed from the long posterior ciliary arteries. Since, other things being equal, arterial pressure decreases in proportion with the number of branchings and the size of the lumen of the vessels, and since the long posterior ciliary arteries and the central artery of the retina are both direct branches of the ophthalmic and are of the same order of size, it would seem probable that the pressure in this arterial circle would approximate that in the branches of the central artery of the retina. Moreover, in a previous paper(11), the close relationship between the pressures in the two circulations—uveal and retinal—under physiological variations has already been pointed out. It is probable, therefore, that we can assume with a fair degree of certainty that the pressures measured in the branches of the retinal artery are not far removed from those in the ciliary body.

We may thus assume that in the ciliary body the arterial mean pressure is about 75 mm. Hg, that the venous pressure is about 25 mm. Hg, while the intra-ocular pressure is about 24 mm. There is thus a fall in the vascular system of about 50 mm. Hg.

Although the blood-pressures in the corresponding organs of the higher animals are generally taken as proportionately equal, the objection may be raised in transferring these measurements to the case of man that the arterial supply of the eye is different in the two cases. It has been noted that in the usual laboratory animals the ophthalmic arteries are derived from both the internal carotid and the external or from an anastomic branch between them: in man it is derived only from the internal. It is very probable, however, that the difference, if any, is in the direction of a higher pressure in the ophthalmic artery of man. In him this vessel comes off as a direct terminal branch of the internal carotid, virtually from the circle of Willis, a vessel which the whole vaso-motor mechanism of the body strives to keep at a high pressure at all times. Further, immediately after the ophthalmic artery has left the internal carotid, the latter vessel constricts, the narrowing being out of proportion to the diminution of its blood stream as judged by measurements of the cross-sections of the vessels (Whitnall(13)), a provision which, by reducing the calibre of the main vessel distal to this important branch and thus damming up the blood stream, will favour the passage of blood down the latter and maintain a high pressure in it. It is probable, therefore, that in man the pressure gradient from arteries to veins is more than 50 mm. Hg.

No method has yet been devised to measure the capillary pressure in the eye. To do so would seem almost impossible, for we have previously seen(11) that any intra-ocular manipulation or pressure applied to the eye at once affects the venous pressure and with it the capillary pressure, the three tending to rise coincidently. This consideration at once rules out the estimations of Niesnamoff(14) and Dieter(15). In default of a direct measurement we must rest content with an indirect estimation based on the measurements of the pressures in the arteries and veins—if, indeed, with their continually changing conditions and wide range of variation it is reasonable to speak of a capillary pressure at all. Most recent estimations show that the capillary pressure is very low; but the majority of these have been undertaken in the skin most of whose capillaries appear to be venous in nature (Krogh(16)). There seems little justification for applying them to the general circulation, and none for applying them to the specialised conditions of the eye. On the other hand it would appear from the work of Dale and Richards(17) and Burn and Dale(18) that the peripheral resistance is not limited to the arterioles, and that the assumption that an abrupt fall in pressure takes place in this part of the circulation is unwarranted; but rather that the fall in pressure is evenly distributed between the smallest arterioles and the first capillaries without a sharp line of demarcation between them. That such a conception is probable is suggested by the influence of the mechanical action of the corpuscles and the contractility of the capillaries as demonstrated by Krogh(16), Lewis(19) and others, and it seems to be substantiated by the recent work of Landis(20), who, using a micro-injection technique such as is followed in this paper, has shown that in the frog's mesentery the fall of pressure does not cease abruptly at the arterioles, but continues to the venous capillaries before flattening.

When it is remembered that the intra-ocular pressure is 20–25 mm. Hg, it would seem that the arterial and venous pressures in the eye bear a relation to the chamber pressure similar to that which the vascular pressures do to the tissue pressure throughout the body generally. The tissue lymph contains about one-half the quantity of colloids that are found in the blood, while the aqueous is practically protein-free. Consequently, if the fluids of the eye can be formed without the intervention of a "secretory" mechanism, the capillary pressure in the eye must exceed the intra-ocular pressure by more than the difference that obtains generally between capillary and tissue pressure. In round figures a difference of 30 mm. Hg must exist in the eye instead of 15 mm. elsewhere. There is every indication that this may be so. In the first place, the ciliary arteries seem to be anatomically peculiar in that they break up almost at once into a rich net-work of capillaries (Fusita(21)), which appear to be capable of such extreme distension of their lumen as to allow the passage of ten corpuscles at a time. In these the lateral pressure will be capable of rising to a considerable height. Again the veins are physiologically constricted at their exits from the eye, and the whole system is confined under a considerable tension within a feebly distensible case, the sclerotic, which will make the vessels approximate in their behaviour to a system of rigid tubes. These considerations will all tend to throw the site of the fall of pressure further towards the veins, and make it probable that the pressure in the arterial capillaries rises at least 30 mm. Hg higher than that in the chamber of the eye, *i.e.* to a total of about 50 to 55 mm. Hg. The vascular pressures, therefore, although by themselves they prove nothing, make it possible that the aqueous humour is formed purely by a process of dialysation.

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