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THE BLOOD-PRESSURE IN THE EYE AND ITS RELATION TO THE CHAMBER-PRESSURE

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THE preceding parts of this article (see BRITISH JOURNAL OF OPHTHALMOLOGY, January and November, 1917) dealt with the blood-stream as a whole, and showed in a general way how it loses lateral pressure in travelling from the left ventricle to the right auricle. From the data thus gained we can now advantageously attack the problem of the blood-pressure in the eye.

The two vascular tracts in the interior of the eye, the retinal and the uveal, are almost entirely separate from each other and must be considered separately. For each tract it will be well to determine, so far as may be possible, first, the arterial entrance-pressure, secondly, the venous exit-pressure, and, thirdly, the relative resistances encountered in the arteries and veins respectively. In so far as we succeed in doing this we shall obtain the data for an estimate of the capillary pressures in these regions.

The blood-pressure in the retina. The retina offers exceptional facilities for the enquiry. It is served almost exclusively by a single arterial and a single venous trunk, and the branches of these

vessels form no anastomoses until the capillaries are reached. Moreover, the distribution of arteries and veins is nearly alike, and over a large part of their course they can be minutely inspected while carrying their normal blood-streams. In the eye of an animal it is possible to ascertain the amount of pressure which, applied to the vessels externally, suffices to arrest the flow of blood through them—an observation comparable to some extent with the measurement of blood-pressure in a limb by means of the sphygmomanometer.

What is the *entrance-pressure* in the central artery? von Schultén, of Helsingfors¹³, obtained direct evidence on this point in his experiments on rabbits. He used albinos so that the choroidal as well as the retinal circulation might be observed. Arranging an ophthalmoscope so as to obtain especially high magnification, he watched the intra-ocular circulation while, by means of an injection-manometer, he gradually raised the pressure in the chambers. The blood-pressure in the carotid of the opposite side was measured at the same time. He found that when the chamber-pressure reached 50 to 60 mm. Hg. the retinal veins were visibly reduced in size, but the artery showed no change. When it reached 90 or 100, or sometimes even 120 mm. Hg., the flow through the central and posterior ciliary arteries became intermittent, the vessels emptying and refilling with the action of the heart: the diastolic blood-pressure was overcome. When it was raised 10 or 20 mm. Hg. higher still the flow was arrested, the blood-column assuming a granular appearance and remaining stationary: the systolic pressure was now overcome. The arresting chamber-pressure in different cases was from 2 to 15 mm. Hg. lower than the carotid blood-pressure on the other side.

According to these observations, the diastolic and systolic pressures in the retinal artery, under the experimental conditions, averaged about 100 and 120 mm. Hg. respectively. But we know that pressure applied to an artery externally, raises the pressure of the blood in the vessel before it arrests the flow (see BRITISH JOURNAL OF OPHTHALMOLOGY, November, 1917, p. 658), and we may be sure that the chamber-pressures reached in these experiments were somewhat higher than the ordinary diastolic and systolic pressures. It seems fairly safe, then, to estimate the mean pressure in the retinal arteries of the rabbit, at their points of entrance, at 90 to 100 mm. Hg. and since various experiments have shown that mean blood-pressures are about equal in many warm-blooded mammals, irrespective of their size, we may reasonably adopt the same estimate for man. We know, be it remembered, that in some human eyes the blood enters the retinal artery at higher pressures than these, for in glaucoma the chamber-pressure occasionally rises to 100 mm. Hg. and even higher (Fourrière,¹⁴ Stock¹⁵), and this could not occur were not the blood-pressure in the eye, even at its lowest point, somewhat higher still.

Leonard Hill's estimate for the arterial entrance-pressure is 100 mm. Hg.¹⁶

A clinical procedure for measuring the blood-pressure in the retinal artery has lately been proposed. Its author, P. Bailliart,¹⁷ tells us that the *technique* is difficult and claims no exactitude for the results so far obtained. But the proposal may well be examined here, for such measurements, if feasible, would have high value in relation both to eye and brain ; indeed, we *must* examine it, for if the results so far obtained are correct, the foregoing estimate is fallacious. The procedure is as follows :

The patient is placed conveniently for ophthalmoscopy and the observer watches the retinal vessels. An assistant, standing behind the patient, makes pressure over the outer commissure of the eyelids, by means of a sphygmomanometer furnished with a small and highly sensitive air-bag. He thus raises the chamber-pressure gradually until the flow through the retinal artery begins to intermit, as manifest to the observer by the emptying and refilling of the artery on the papilla, and often to the patient by a pulsatile disturbance of his vision. When this stage is reached the chamber-pressure equals the *diastolic* pressure in the artery ; the air-bag pressure is noted. Then, in the same way, the assistant continues to raise the chamber-pressure until the flow is arrested, the arrest being known to the observer by the granulated and stationary condition of the blood-column and to the patient by the total darkness of the eye. At this stage the chamber-pressure equals the *systolic* pressure in the artery ; the air-bag pressure is again noted.

So far the procedure is comparable with that of von Schultén ; the essential difference is still to come. It lies in the way of determining the chamber-pressure at the stages mentioned. Schultén measured it directly by the manometer ; Bailliart infers it from the pressure in the air-bag that presses on the eye. He does so in this way. He assumes that the pressure in the eye at any given moment may be found by adding the pressure in the air-bag to the normal or initial pressure in the eye. For example, finding the air-bag pressure to be 47 mm. Hg., at the moment when intermittency begins, and assuming the normal chamber pressure to be 20 mm. Hg., he adds these two amounts together and concludes that the chamber-pressure at that stage is 67 mm. Hg. ; this, then, is the diastolic pressure in the artery. The systolic pressure is determined in like manner.

Is this simple summation-method to be trusted ? Or, to widen the question, is it possible either in this way or in any other to infer the rise of pressure in an eye from the rise of pressure in an air-bag pressed against it ? We made experiments on the point. The apparatus employed is shown in Fig. 41.

FIG. 41.

A and B are two thin-walled rubber balloons. Normally they are of equal size, but one can be made smaller than the other by partly confining it in a short piece of strong rubber tube (C). Each is connected with a water-manometer giving a column 90 cm. in height (=66 mm. Hg.). The tubes are of small bore (2.5 mm.), so that when the balloons are compressed the pressure rises rapidly without much expulsion of air. Each scale is set so that its zero corresponds with the level of the water when the latter is equal in the two limbs of the manometer. The readings show the total height of the water-column above and below zero.

At the outset of each experiment the pressure in each balloon is brought to the desired height by blowing through the side tube T and then allowing air to escape until the water-column sinks to that point. The figure shows a pressure of 10 cm. in each balloon.

The desired internal pressures having been thus established, and found to suffer no loss through leakage, A is placed on B and pressed down upon it by means of a flat glass plate (D). The pressure in A is driven up by steps of 10 cm., and at each step the corresponding pressure in B is noted. In this way the pressure-changes occurring simultaneously in the two balloons when one is pressed against the other are ascertained.

In some of the experiments balloon B was replaced by an ox-eye filled with air; the optic nerve having been tunnelled, the vitreous was carefully squeezed out and a glass canula tied in. In certain other experiments the lower balloon or the ox-eye was filled with water instead of air, care being taken that the water expelled during compression did not add directly to the length of the water-column.

The results, each based on several trials, were charted. Perplexing at first,* they gradually fell into intelligible order and may be summarized as follows:

FIG. 42.

Pressure-lines obtained when balloons varying in size were pressed together, the initial internal pressures being equal.

FIG. 43.

Pressure-lines obtained when a balloon and an eye-ball of equal size were pressed together, the initial internal pressures being equal.

* If the results perplex the reader, as they did the writer, the following may be helpful:

When a flat plate of a certain weight is laid on a balloon it flattens the wall of the latter over a certain area and comes to rest; its weight is balanced by the internal pressure acting upwards against the flattened area.

In the flattened area the tension of the membrane acts in a direction perpendicular to the upward and downward pressures, and therefore neutralizes no part of either. Hence, provided the membrane is perfectly flexible, the external pressure is an exact measure of the internal. This is the principle of applanation-tonometers, and these instruments fail only because the area of contact cannot be precisely measured and the wall of the eye is not perfectly flexible.

How is it, in the case of two balloons, that the internal pressures can differ on the two sides of the flexible partition which is their area of contact? The explanation is that *the partition is not flat*. It is convex towards the balloon of lower internal pressure, and the excess of pressure on its concave surface is balanced by the tension of the membrane. Only when the pressures on its two sides are equal is the partition flat. We were able to demonstrate this by substituting for one of the balloons a glass funnel with a half-balloon tied over it; the partition was then visible through the glass.

1. When the two balloons were alike in *size*, alike as to *substance*, and alike as to *initial internal pressures*, and were pressed together between two similar surfaces, e.g., two flat plates or two shallow cups, the rise of pressure was approximately the same in both. Usually it differed a little, no doubt because no two of the balloons employed were exactly alike.

2. When the balloons differed in *size*, but were alike in other respects, the rise of pressure was greater in the smaller balloon.

FIG. 44.

Pressure-lines obtained when the initial internal pressures were unequal.

FIG. 45.

Here the balloon rests only in part upon the eye.

Figure 42 shows the influence of size. The circles indicate the relative sizes of the balloons employed—roughly only, for the balloons were not quite spherical, and their average diameters could not be exactly determined. In the first experiment A and B were of equal size, and while the pressure in A was driven up step by step from 10 to 50 cm., that in B rose to the same extent; the pressure lines for A and B were almost identical. In the second experiment A was larger than B¹, their diameters being roughly as 3 to 2; they gave the lines A and B¹. In the third, A was smaller than B², roughly as 2 to 3, and the lines were A and B².

3. When a rubber balloon and an ox-eye filled with air, the two being made as nearly alike in size as possible, were pressed together, then in spite of equal size and equal initial pressure the rise was greater in the eye than in the balloon (see Fig. 43, lines A and B¹). Here the essential difference lay in the *substance of the membranes*, the rubber being much more extensible than the sclera; under compression the balloon showed much more lateral expansion than did the eye. The significance of the dotted line is given later.

4. When, the other conditions being equal, the *initial internal pressures* differed, the higher pressure line at first rose less rapidly than the lower, and then tended to take the direction which it would have taken had the initial pressures been equal. Thus A and B¹ (Fig. 44) were two rubber balloons with initial internal pressures of 0 and 20 cm., and of approximately equal size when these pressures were established. They gave the lines A and B¹. A and B² were a balloon and an ox-eye of approximately equal size and having initial pressures of 0 and 20 cm. as in the previous case; they gave the lines A and B². Then the balloon was made a little larger than the eye, roughly as 3 to 2, and the lines were A and B³.

5. When the lower balloon, or the ox-eye, as the case might be, was filled with water instead of air, the results were about the same as when air was employed; an essential difference was not discovered.

It is evident that any attempt to infer the chamber-pressure in an eye from the pressure in an air-bag pressed against the eye encounters formidable difficulties. Can they be surmounted? Even if one could obtain an air-bag equal to the human eye in size, in flexibility, and in extensibility—say, a small rubber balloon strongly jacketed with silk—and were to make the pressure in this bag equal to that in the eye to start with, there would still be an obstacle; the air-bag would expel a part of its contents during compression, while the eye would be comparatively closed. And if this obstacle were overcome, a greater would remain. If the air-bag were pressed against the eye in such a way as to leave the pupil free for observation of the fundus, it would necessarily press more or less on the margin of the orbit as well as on the eye, and this would largely influence the result. Thus in Fig. 43, the upper line was obtained when the balloon rested only on the eye, the dotted line when it rested partly also on a small china pot as shown in Fig. 45. When two similar balloons were used in like manner there was a similar discrepancy, and the discrepancy varied in amount according to the bearing of the balloon on eye and pot; it could be made very large. One must conclude, with regret, that a trustworthy measurement of retinal blood-pressure cannot be achieved in any such way.

The estimate given above may therefore stand; *the pressure in*

the central artery at its point of entrance is probably from 90 to 100 mm. Hg.

What is the *exit-pressure* in the central vein? It cannot be permanently lower than the pressure in the chambers. In many eyes the two appear to be about in equilibrium, for the vein at its exit collapses with each arterial pulsation. The arterial wave, by expanding the intra-ocular arteries, adds to the content of the globe and thereby raises the chamber-pressure for the moment above the venous pressure at its lowest point, and at that point the vein collapses. Between the arterial waves the chamber-pressure falls to its previous level and the vein refills. Blood-pressure and chamber-pressure appear to be so nearly balanced at this point that each in turn overcomes the other. In the large majority of eyes, however, the vein does not collapse, and in these, therefore, the exit-pressure must be higher than the chamber-pressure, even when the latter is at the summit of its pulsatile rise. But how much higher?

In normal eyes the pulsatile rise is commonly not more than 2 mm. Hg. (A. J. Ballantyne¹⁸), and yet it suffices in many cases to close the vein; hence one is tempted to conclude that the difference between chamber-pressure and venous exit-pressure in the general run of eyes must be very small. I adduced this argument in the discussion already referred to (BRITISH JOURNAL OF OPHTHALMOLOGY, 1917, p. 4), but further consideration shows that it is not quite safe. The collapse of the vein occurs in a seemingly capricious manner; not only in normal eyes, but in eyes of high tension also, it is sometimes present and sometimes absent without obvious reason. What are the determining conditions?

The collapse is due essentially, as already said, to the arterial pulsation. This latter depends in part on the extensibility of the arteries, being greater when they are elastic than when they are rigid; hence, perhaps, the fact that the collapse is seen more frequently in children than in adults, but why is it so pronounced in certain children and quite undiscoverable in others? Again, other things being equal, the amplitude of an arterial pulse is greatest when the external pressure on the wall of the vessel approximates to the internal pressure; this is proved by the behaviour of the sphygmometer-index when the pressure in the armlet rises nearly to that in the underlying artery; hence it is that in certain eyes one can induce the venous collapse by external pressure. But this again is the exception and not the rule. A determining factor is still to seek.

It appears to lie in some cases, at least, in the mutual relations of the artery and the vein in the neighbourhood of the papilla. Any juxtaposition that leads to *direct* compression of the vein by the expanding artery favours collapse of the vein between the point of compression and the point of exit, and for this reason: above

the point of compression the oncoming venous stream is for the moment checked ; below that point *its pressure is for the moment lowered*. Examples are given in Figures 46, 47, and 48, which are here reproduced from a work of my own published many years ago.¹⁹

Fig. 46.

Fig. 47.

Fig. 48.

Sketched from eyes in which the central vein collapsed. The collapse occurred in the parts indicated by the letter C. The arrows point towards the fovea. Erect image.

Fig. 46 from an eye with premonitions of congestive glaucoma. T.+1? Two arteries cross the vein. In no other place in either eye did an artery overlie a vein near to the papilla, and nowhere else was a collapse discoverable. The tension of the two eyes was alike to finger and tonometer.

Fig. 47 from a healthy eye. The collapsing vein is crossed by overlying arteries in three places. There was no other such crossing near to the papilla in either eye, and no other vein collapsed.

Fig. 48 from a healthy eye, with myopia of 5D. and small myopic crescent. The disc-half adjacent to the crescent is deeply recessed, so that the veins remain subject to the chamber-pressure after they bend backwards. Their contact with the arteries at the bends suggests that they were compressed here during the expansion of the arteries. Collapse was obvious at C, just discoverable at C1.

An artery may compress a vein in other parts of the retina, and a thickened artery may seriously obstruct it (Marcus Gunn),²⁰ but only near to the papilla, so far as I know, does it induce a rhythmic collapse. The reason is not far to seek. The pulsatile rise of chamber-pressure falls impartially on the whole retina; nowhere can one portion of a vein dilate in order to allow an adjacent portion to collapse; but beyond the exit-point the vein is no longer subject to the chamber-pressure, and into this part a sudden expulsion of blood is possible. The idea that anatomical peculiarities at the papilla determine the occurrence of the venous collapse is far from being new. In the first number of his *Archiv* (1854, p. 386), von Graefe, though he did not refer to crossing of the vessels, ascribed the variability of the venous pulse to variations in the relations of the vessels to the optic nerve.

Now, if the collapse in question is commonly determined by a localized lowering of the venous pressure in this way, it is clear that we must not take it as a proof that in other eyes which exhibit no collapse the venous exit-pressure and the chamber-pressure are very nearly balanced. In the general run of eyes, and indeed in these others also, except at the moment of collapse, the exit-pressure may, so far as this evidence goes, be some mm. Hg. higher than the

chamber-pressure. In eyes of very low tension it certainly is so; thus, in presence of a leaking corneal wound, the chamber-pressure sinks almost to zero, while the pressure in the central vein does not fall below that in the veins of the orbit. In eyes of high tension, unless the vein collapses, the exit-pressure still overtops the chamber-pressure even at the summit of its pulsatile rise, and this rise is sometimes very considerable (Ballantyne).¹⁸ The pressure in the central artery, of course, is always greater than that of the intra-ocular fluid, and always drives the venous pressure up till it overcomes the chamber-pressure; in the most intense glaucoma the retinal circulation, though much retarded, is never brought to a standstill.

All that we can safely say, then, is that *the exit-pressure in the central vein is somewhat higher than that in the chambers of the eye, the difference, probably, being small*. It is noteworthy that Leonard Hill,¹⁶ experimenting on dogs, found the pressure in the torcular Herophili, the main venous outlet of the skull, to be equal to that of the cerebro-spinal fluid.

Now, what is the average *chamber-pressure* in healthy human eyes? In rabbits, cats, and dogs, many direct measurements have been made by means of the manometer. Leber²¹ collated these observations in 1903, distinguishing those made without narcosis from the others. The pressure was generally between 20 and 30 mm. Hg., but occasionally a little above or below these limits. For the rabbit, without narcosis, he put the mean provisionally at 25 mm. Hg.; for the cat, at 28 mm. Hg. In a single case, Wahlfors,²² of Helsingfors, applied the manometer, with von Schulten's special precaution against disturbance of the pressure (the air-bubble in the horizontal tube), to a healthy living human eye doomed to excision; the pressure was 26 mm. Hg. A large number of observations on healthy human eyes with the Maklokov tonometer gave 25 as the probable mean. On these grounds Leber estimated the mean for the human eye provisionally at 25 mm. Hg.

The Schiötz tonometer, according to nearly all observers, appears to indicate a lower mean. Cridland²³ tested 1001 healthy eyes and found the mean to be 20.06; he found, moreover, that previous observers in the aggregate had obtained nearly the same result—19.1. At first glance this broadly-based statistic seems conclusive, but one must distinguish between *readings* given by the instrument and *mercury-equivalents* offered by the chart. We now know that for normal eyes the average reading is about 4.3 degrees, but we do not know with certainty the average mercurial equivalent for that reading. Clinicians sometimes forget that the figures which they set down so confidently rest, of necessity, on uncertain evidence. I have elsewhere discussed this question in detail and recorded some experiments relating to it²⁴; a few points only need be re-stated here.

Professor Schiötz²⁵ has told us exactly how he obtained his curve.

He tested 8 excised human eyes, each under 11 different degrees of intra-ocular pressure. In each case a known pressure was established in the eye by means of a manometer, the connecting tube was then closed, and the tonometer was applied. In this way, for each degree of internal pressure he found a corresponding tonometer reading. It was not to be expected that for any given pressure the 8 eyes would all give the same reading, for the impressibility of the eyeball varies not only with the intra-ocular pressure, but also with the character of the envelope; naturally, the eyes gave various readings. For example, with an internal pressure of 25.7 mm. Hg. (35 cm. water) the average reading was 2.8, but one of the eyes gave 1.8, and one gave 4. The curve, of course, was based upon the averages. It is only by such experiments in the laboratory or the mortuary, or by rare observations like that of Wahlfors, that mercury equivalents for tonometer-readings can possibly be obtained.

Professor Schiötz offered his curve expressly as giving *approximate* mercury equivalents based on *averages*. Less cautious workers have used it as though it gave precise equivalents in the case of individual eyes. Take the figures just quoted, and consider the kind of error into which the unwary clinician may fall. He tests a patient's eye, obtains a reading of 1.8, and records it as 30.5 mm. Hg. He tests another patient's eye, gets a reading of 4, and records it as 21 mm. Hg. According to his records there was a difference of 9.5 mm. Hg. in the intra-ocular pressure of those two eyes, whereas in reality there was possibly no difference at all; they both may have had a pressure of 25.7 mm. Hg., and have differed only in the character of their envelopes. What an eye-tonometer *can* do the Schiötz instrument does with unrivalled accuracy, but it cannot achieve impossibilities. It can measure *changes of pressure* in an individual eye with great precision, e.g., the amount of the pulsatile rise, but it cannot determine *absolute pressures* with nearly the same certainty. The curve, even if it were demonstrably correct for averages, would still leave us in some doubt over each individual eye.*

*I have suggested that clinicians should record their readings and not the supposed mercury equivalents; the reading is a fact, whereas the other is an inference which may be correct or incorrect. In his original paper Professor Schiötz set the example of so doing. Some authorities now write 35 (Schiötz) instead of 35 mm. Hg. Perhaps this is the better plan, for while it asserts a fact it also suggests the probable equivalent. But is a chart really needed? I hazard the prediction that the ultimate form of the Schiötz tonometer for clinical work will be a little different from the present. It will be an instrument of one weight only: the scale will deal with pressures ranging approximately from 15 to 50 mm. Hg.—pressures outside these limits hardly need measuring; the divisions of the scale will diminish in size progressively from one end to the other, so as to correspond with equal increments of intra-ocular pressure, say, 5 mm. Hg., and will be numbered 15, 20, 25, and so on up to 50; over them will stand the words "approximate equivalents in mm. Hg." The record will be taken directly from the scale and be written as 35 (Schiötz) or whatever it may be. There will then be no pitfall for the unwary.

The point with which we are here concerned is the probable mercury-equivalent for Cridland's average reading of 4.3 degrees. The Schiötz curve puts it at 20 mm. Hg. My own tests put it at about 24 mm. Hg. My experiments were made with a tonometer which Professor Schiötz had been so kind as to test for me. They resembled his own, except that they were made in the mortuary on eyes remaining in the orbit instead of excised eyes. They were made on twelve eyes in seven individuals. In both cases the number of eyes tested was small and individual variations were considerable, so that one could not expect the averages to agree exactly, but the discrepancy appears to have been due to something more than chance. With a low intra-ocular pressure (17.6 mm. Hg.) my average reading differed from that of Professor Schiötz by two degrees; with progressively higher pressures it differed less and less; until with a pressure of 40 mm. Hg. the discrepancy disappeared. I suggest, though I cannot prove, that the discrepancy was partly due to the conditions under which the eyes were tested.

The sclera of an eyeball in the orbit receives some support from the surrounding tissues, and is, therefore, less fully extended by a given external pressure than is that of an excised eye; hence, under the weight of the tonometer, it is able to yield a little more: the displaced fluid is more easily accommodated, the impression a little deeper. The difference will be more pronounced when the pressure is low than when it is high, for in the former case the pressure in the eye will differ comparatively little from that of the orbital tissues, and will be borne by them to a considerable extent, whereas in the latter it will be much the higher of the two, and will be borne in larger proportion by the sclera itself. In an excised eye it is borne entirely by the sclera. This would explain the fact that my averages differed less and less from those of Professor Schiötz as the intra-ocular pressure was increased.

On these grounds I venture to suggest that for low and normal intra-ocular pressures Professor Schiötz's readings were somewhat too high, in other words, that his curve puts the mercury-equivalent for a given pressure a little too low. In no case, of course, can readings given by dead eyes be adopted with entire confidence for living eyes; but it is probable, I think, that for Cridland's average reading of 4.3 degrees the average mercury-equivalent is about 24 mm. Hg. This estimate, it will be noticed, falls better into line with the results of direct manometric measurements in the eyes of animals.

Taking 24 mm. Hg. as the average chamber-pressure, and knowing that the pressure in the central vein is somewhat higher than this latter, we may conclude that *the exit-pressure in the central vein is on the average not less than 25 mm. Hg.*

According to these estimates, the end-pressures in the central

artery and vein are respectively about 95 and 25 mm. Hg., and the total fall of pressure in the retinal vessels is about 70 mm. Hg.—about as much as in the vessels of a finger (BRITISH JOURNAL OF OPHTHALMOLOGY, 1917, p. 666). How much of this fall takes place on the arterial side of the half-way point and how much on the venous? The falls in the two halves of the circuit are proportionate, we know, to the resistances encountered, and the ratio of the resistances can be determined from the relative sizes of the arteries and veins—provided the two sets of vessels, though differing in size, are alike as to number and manner of distribution (BRITISH JOURNAL OF OPHTHALMOLOGY, 1917, p. 18).

In his work on the circulation and nutrition of the eye, Leber²¹ says that the diameter of the central artery is to that of the central vein about as 2 to 3, or 3 to 4 (Fig. 49), and that the same ratio is maintained throughout their ramifications. If this is so, then the *cross-sections*, being as the squares of the diameters, are about as 4 to 9, or 9 to 16, or, if we split the difference, about *as 1 to 2*. This is the ratio that has been found for the cross-sections of arteries and veins in other regions of the body, but before using it as a guide to the capillary pressure in the retina one must consider the provision mentioned above concerning number and distribution.

FIG. 49.

Shows the relative widths of retinal arteries and veins according to the figures given by Leber.

The relations of the larger retinal trunks may be studied in many good published drawings of the fundus, and for a general view of their ramifications over the whole retina the reader may consult a drawing by Langenbacher reproduced by Leber. For microscopic views of arterioles, venules, and capillaries, he may turn to two drawings, also from Leber, that appeared in the preceding part of this article (BRITISH JOURNAL OF OPHTHALMOLOGY, 1917, p. 674). These I can now supplement by photographs of the ultimate ramifications in the retina of the ox (Figs. 50, 51, and 52).

FIG. 50.

FIG. 50.—Retinal vessels of ox injected with carmine-gelatine. V, vein. A, artery. Springing from the artery about half-way up is a branch passing across the picture towards the vein; many of its capillaries cross the vein before reaching the corresponding venules. Springing from the vein are branches passing across towards the artery and beyond it; under the microscope they are easily distinguishable from the artery at the points of crossing. $\times 30$ diams.

(From a preparation and photograph by Mr. F. C. Lowe).

FIG. 51.

FIG. 51.—From the same specimen as Fig. 50. It shows the ultimate branches of three arterioles, the three corresponding venules, and their connecting capillaries. $\times 30$ diams.

FIG. 52.

FIG. 52.—The central area of Fig. 51 more highly magnified. The arterioles and venules, together with the beginnings and endings of the capillaries, lie in one plane and are well-defined, whereas parts of the capillaries lie in a different plane and are ill-defined; when the latter parts are focussed they appear no larger than the others. $\times 60$ diams.

For these photographs and the preparations, and for others which will appear in the final part of this paper, I am indebted to Mr. F. C. Lowe, of Wednesbury, who, in leisure hours is not only a skilled microscopist and photographer, but as an amateur histologist has made admirable injection-preparations of the vessels of the eye. Hearing of my requirements he most generously offered his help.

Examined in detail the arteries and veins show many differences: the bifurcations take place at different distances from the papilla, and the branches do not match exactly; but there is a very evident general correspondence over the whole area of the retina. This is more manifest perhaps in the smaller ramifications than in the larger, and for the present purpose it is more important here because it is in the smaller channels that the fall of pressure is most rapid. In Figure 50, at the top, one can compare a venule passing across from left to right with the corresponding arteriole below it passing from right to left; below this again is a horizontal venule, and below that, not seen in the photograph, is an arteriole closely corresponding with it. In Figure 51 one sees the final branching of three arterioles and three corresponding venules. Figure 52 shows a larger view of the central area of the same. It is important also that neither arterioles nor venules have any anastomoses amongst themselves; they are connected only by their capillaries (Leber).

In view, then, of their general symmetry of distribution, we shall

probably make no great error in computing the relative resistances from the relative cross-sections of the arterial and venous halves of the circuit.

If the cross-sections are as 1 to 2, the resistances are as 4 to 1; in other words, the fall on the venous side is one-fifth of the total fall. With a total fall of 70 mm. Hg., the venous fall will be 14 mm. Hg. Adding this amount to that of the chamber-pressure we get 25+14, or 39 mm. Hg., as the pressure at the half-way point.

Let us now allow a margin for uncertainty in the data. We put the entrance pressure at 95. Leonard Hill¹⁶ puts it at 100. Let us now put it at anything from 90 to 110. Then the total fall, instead of 70, will be anything from 65 to 85, and the half-way pressure, worked out as before, will be from 38 to 42 mm. Hg. Let us widen the margin further by embracing Leber's alternative figures for the relative diameters of arteries and veins. This will put the venous fall at anything from one-sixth to one-fourth of the total fall, and the half-way pressure at anything from 36 to 46 mm. Hg.

Assuming these data to be fairly trustworthy, we may conclude, then, that *in a healthy eye with a chamber-pressure of 24 mm. Hg. the pressure in the retinal capillaries is probably not far removed from 40 mm. Hg.*

The pressures in the uveal tract, and the bearing of these estimates on questions of secretion and absorption in the eye, will be considered in the fourth and final part of this article.

(To be concluded.)

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