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COMMUNICATIONS

TONOMETRY

BY

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CHRISTIANIA

(Concluded)

Further experiments were undertaken with a rubber bag having the size and shape of an eye, and fitted above with a ring to carry the membrane ordinarily used on the drum. At low water-pressures the difference between the deflection for open and closed connections was very small; at higher pressure and with larger weights it was nil. See Table VI.

If graphs are constructed from Table V. the deflections of the pointer being marked on the abscissa and the pressures in cm. on the ordinates, the top graph will be that of the open drum, congruent with it will be the graph of the closed rubber bag, and only a little below these will come the graph of the rubber bag with the rubber glove. The graph of the closed rubber tube will lie considerably lower, and finally the graph of the closed drum will be the lowest of all.

We thus see that when the tonometer is applied to a vessel with very extensible walls *the same deflections are obtained whether the*

vessel is closed or in open connection with the manometer, the elasticity of the walls equalizing the weight of the tonometer. With more rigid walls the deflections show a decided difference in the two cases, and this difference is greatest when the walls are absolutely rigid.

As the sclera possesses a certain extensibility and as this latter may be safely assumed to vary to some extent owing to varying thickness and other causes, it is evident from what is stated above, that *the same index deflection does not in all eyes represent the same internal pressure.* As was found by experiments on dead eyes, the deflections given by the same pressure will vary somewhat, and we shall find maximal and minimal values for them.

TABLE VI
DEFLECTION OF INDEX

Pressure H ₂ O.	5.5 gram.		10 gram.	
	Open.	Closed.	Open.	Closed.
25 cm.	18 mm.	14.8 mm.	—	—
30 "	9.9 "	7.5 "	—	—
40 "	2.9 "	2.5 "	19 mm.	16 mm.
50 "	1.4 "	1.3 "	10 "	10 "
60 "	0.8 "	0.8 "	6.5 "	6.5 "
70 "	0.4 "	0.4 "	4.5 "	4.5 "
80 "	—	—	3 "	3 "
90 "	—	—	2 "	2 "
100 "	—	—	1.5 "	1.5 "
110 "	—	—	1+ "	1+ "
120 "	—	—	0.7 "	0.7 "

The upward limit would be the deflections given by eyes in open communication with the manometer, and who knows whether in some cases the values may not be very close to these. I have in my mind the large, very thinly walled buphthalmic eyes which with the tonometer do not always show any specially high pressure, that is to say the necessary weight is not so heavy nor are the index deflections so slight as might have been expected. If this deflection, however, had been noted on the "open eye," it would have meant a much higher pressure.

Further, I have in mind a rare case of progressive glaucoma simplex in a comparatively young man, where the deflection was 5 mm. with the 5.5 gram. weight (5.5/5). He had large globes with a myopia of 18 D. Now 5.5/5 on the usual graph means a pressure of 18 mm. Hg., on the open graph it signifies over 33 mm. Hg.

Fortunately, the differences do not appear on the whole to be very great, though greater than is desirable. Strictly speaking, each graph

represents the values for the eye experimented on and for no other,¹ and when in spite of this fact we construct graphs according to the average values obtained from the maxima and minima, it should be kept well in mind that they are approximate values only. As pointed out by Priestley Smith, we have here the limitation of the tonometer, and the fact cannot be altered as long as we employ the principle in question. I cannot imagine any method available for living eyes by which the errors due to variations of the envelope could be eliminated.

Below I give the maxima and minima, and also the average values obtained by Priestley Smith's measurements of 12 eyes *in situ*, by my own previous measurements of 8 enucleated eyes, and by my latest measurements of 10 eyes *in situ*.

TABLE VII

Index Deflection (d).	Priestley Smith.			Own previous.			Own recent.		
	Max.	Min.	Middle.	Max.	Min.	Middle.	Max.	Min.	Middle.
d = 1 mm.	40·8	33·4	37·2	41	29·5	35·5	44·3	38·5	41
d = 2 „	36	29·5	32·4	37	26	29·5	40	34	36·2
d = 3 „	32	25	28·5	29·5	22·5	25	35	29	31·5
d = 4 „	28·7	22·2	25	25·5	18	21	31·7	25·4	28
d = 5 „	23	17·7	19·5	18	12·8	15·5	25	19·2	21
d = 6 „	18·4	13	15·5	13	9	11·5	19	14	17

We will now consider the second factor affecting the deflections, viz., the membrane on which the foot part of the instrument rests. It is obvious that variations in thickness and elasticity in this membrane must influence the depth of the impression made by the plunger. In order to investigate this point, I have used experimentally as cover for the drum a cornea 0·6 mm. thick, a rubber membrane, 1·133 mm. thick, and a rubber membrane of 0·5 mm. thick.

Table VIII gives the values for a graph of the open and closed drum respectively, with these various membranes, using a weight of 5·5 grm.

With regard to the open drum, the variation in the deflections can only be due to the nature of the membrane, all other conditions being identical in the three cases.

If the values given in Table VIII A are made into graphs, the top graph will be that of the cornea, with a comparatively even decline intersecting the others at the level of 70 cm., with zero at 77 cm. water-pressure. The two other graphs lie lower, the intervals between them being about equal (in each case about

¹Arch. f. Augenheilk., Vol. LII, Part 4, p. 411, 1905.

10 cm.), until both rise steeply, with zero at 90—100 cm. water-pressure. The graph of the thicker rubber membrane is lowest.

It is noteworthy that although it is the thickest of the three the cornea offers the least resistance to the plunger. I presume the reason is that the rubber membranes on account of their elasticity offer a stronger resistance than the cornea, which is more in the nature of a piece of soft skin. That is why the cornea gives a zero point which is much more easily defined than when experimenting with membranes which stretch under the higher pressures, and also yield but little to the plunger. The spherical radius of the

TABLE VIII.

A. Open Drum. Deflection in mm.				B. Closed Drum. Deflection in mm.			
Pressure H ₂ O.	Cornea 0·6 mm.	Rubber Mem- brane 0·113 mm.	Rubber Mem- brane 0·5 mm.	Pressure H ₂ O.	Cornea 0·6 mm.	Rubber Mem- brane 0·113 mm.	Rubber Mem- brane 0·5 mm.
15 cm. ...	—	—	15 mm.	0 cm. ...	8 mm.	—	—
20 „ ...	—	18·5 mm.	8 „	5 „ ...	5 „	15·2 mm.	9·5 mm.
30 „ ...	15 mm.	8 „	4 „	10 „ ...	3·5 „	10·8 „	6·6 „
40 „ ...	8·1 „	4·2 „	2·55 „	20 „ ...	1·4 „	5·8 „	3·3 „
50 „ ...	5·1 „	2·6 „	1·8 „	30 „ ...	0·45 „	3·7 „	2·3 „
60 „ ...	2·7 „	1·6 „	1·3 „	40 „ ...	-0·3 „	2·2 „	1·6 „
70 „ ...	1 „	1·1 „	0·9 „	50 „ ...	—	1·4 „	1·2 „
80 „ ...	-0·4 „	0·5 „	0·6 „	60 „ ...	—	0·9 „	0·8 „
90 „ ...	—	—	0·4 „	70 „ ...	—	0·7 „	0·75 „
				80 „ ...	—	—	0·25 „
				90 „ ...	—	—	0 „

cornea does not vary at an increased pressure; it remains the same whether the water-pressure is 10 cm. or 130 cm. The rubber membranes, on the other hand, undergo alterations, the 0·133 mm. membrane being over-distended at a pressure of 90 cm. The radius changes evenly from 11·6 mm. at 10 cm. water-pressure, to 7·25 mm. at 70 cm. water-pressure. At 80 cm. it begins to distend.

If graphs are drawn for the closed drum also (Table VIII B), the remarkable result will be that the cornea graph is here the lowest of the three. The graphs of the thinner and the thicker rubber membranes lie respectively 17 cm. and 13 cm. below their open graphs, and the cornea graph lies 40 cm. below its open graph. The reason must presumably be that in the case of the rubber the narrow edge round the foot of the tonometer yields a little before the inner pressure, and thereby permits the plunger to enter more deeply than in the case of the cornea; the scleral edge of the latter evidently does not yield to the inner pressure at all.

When with open communication we obtain different deflections

on different eyes, the reason can only be the varying resistance in the cornea, either owing to varying thickness or to other causes, and these will, of course, influence the closed eye also, and lead to variation of deflection in various eyes.

The Foot Piece

The deflections of the pointer will be influenced by the curvature as well as by size of the foot. If the spherical radius of the foot is made less than that of the cornea, the plunger will never be pushed up fully, and even with the highest intra-ocular pressures the pointer will show a certain deflection. It should always be greater than that of the cornea in order to ensure the mutual adaptation of the central parts of the foot and the cornea.

If the size of the foot is altered the deflections will be altered. In my tonometer the lower surfaces of the foot and plunger together have an area of 84 sq. mm. If this surface were reduced to, say, 50 sq. mm., the deflections would be perceptibly reduced. The weight of the cylinder (10 grm.) would then rest on a smaller supporting area, a higher internal pressure on each sq. mm. of this area would be needed to counterbalance the weight, and the deflections would decrease in consequence.

For this reason I had difficulty in adjusting a tonometer whose foot-surface was reduced for the purpose of measuring eyes with *ulcus serpens*. I had to increase the loose weight by half a gramme in order to make the measurements agree with those of the standard tonometer.

A theory has been advanced that the size of the eye affects the readings of the tonometer, wider deflections of the pointer being obtained from large eyes than from small eyes. The experiments described above prove conclusively that the volume of the eye *per se* is of no importance, but the large eye has a larger wall surface than the small eye, and as the yielding of the wall is the decisive factor with regard to the deflection, the latter will necessarily be greater for a large eye than for a small one, other conditions being similar.

Another point must be remembered in measuring small eyes. Very small eyes have small corneas with small spherical radii, and in such cases the foot of the tonometer will not be in contact with the cornea to its full extent. The results will be the same as if the foot were smaller; the deflections will be smaller and the pressure will appear greater than it really is.

Finally, it is important that the upper point of the plunger should touch the short arm of the lever at a point exactly 4 mm. from the fulcrum. If the point of the contact is farther off, the deflections will be smaller; if it is nearer, they will be greater.

Tonometer Graphs

In my first work ("Ein neues Tonometer," *Arch. f. Augenheilk.*, Vol. LII, Part iv., 1905), graphs were given only for the open eye. Fairly numerous measurements on healthy, living eyes had shown me that the upward limit for the normal pressure was a deflection of about 3 mm., and I considered myself justified in stating that a slighter deflection than this was a reason for careful watching of the eye in question.

In my second work ("Tonometrie," *Arch. f. Augenheilk.*, Vol. LXII, Part iv, 1909), the difference between the graphs of open and closed eyes was demonstrated, and fresh graphs were given showing different values in mm. Hg. for the deflections. I expressly stated, however, that these altered values would not falsify the import of the deflections: deflections between 3 mm. and 6 mm. would still, as before, indicate normal pressure in the eye.

As might have been expected, the graphs based on measurements of 8 enucleated eyes prove to have been incorrect; the measurements taken by Mr. Priestley Smith of 12 dead eyes *in situ*, and my own later measurements of 10 eyes give a mean value which lies somewhat higher.

TABLE IX.

Priestley Smith. 5.5 grm.				Schiötz. 5.5 grm.			
Pressure in mm. Hg.		Deflection in mm.		Pressure in mm. Hg.		Deflection in mm.	
17.6	...	...	7	10	...	...	12.3
25	...	...	4	20	...	...	6.5
32.4	...	...	2	30	...	...	3.3
39.7	...	...	0.4	40	...	...	1.15
				46	...	...	0

If graphs are drawn according to these values and compared with my previous graphs (Schedule II), the following mean values will be found for the various deflections:

TABLE X.

Priestley Smith.				Schiötz.			
Deflection in mm.		mm. Hg.		Previous values. mm. Hg.		Later values. mm. Hg.	
0	...	...	42.2	43	...	...	46
1	...	...	37.8	35.5	...	...	41
2	...	...	32.4	29.5	...	...	36.2
3	...	...	25.8	25	...	...	31.5
4	...	...	25	21	...	...	28
6	...	...	19.5	15.5	...	...	21
8	...	...	15.5	11.5	...	...	19

It will be seen that Priestley Smith's values at low pressure are lower than my previous values, the difference decreasing with higher

pressures so that the graphs would practically meet at a deflection of 0. My later measurements, as mentioned above, yield values somewhat higher than those found by him.

In Table XI, I give my later measurements with weights of 5.5 grm. and 7.5 grm. Those taken with weights of 10 and 15 grm. were too few for mean values to be computed from them.

TABLE XI.
INDEX DEFLECTIONS IN MM.

Water Pressure in cm.				5.5 grm.		7.5 grm.	
				Open.	Closed.	Open.	Closed.
10	...	...	...	—	15	—	17.4
15	...	...	...	—	11.8	—	14
20	...	...	...	—	9.2	—	11.6
30	...	...	...	12	5.75	17	8.6
40	...	...	...	7.3	3.7	11.2	6.7
50	...	...	...	4.1	1.9	7.7	4.9
60	...	...	...	1.6	0.35	5.4	3.2
70	...	...	...	0	—	3.5	1.85
80	...	...	...	—	—	2	0.6
90	...	...	...	—	—	0.9	—

As will be seen, I measured the open eye also. To this end as much as possible of the vitreous was pressed out, and the eye was thereby perhaps rather roughly handled; this may have influenced the results to some extent.

Mr. Priestley Smith's measurements were conducted in a more gentle manner; they dealt with the "closed" eye only and with the 5.5 grm. weight, one series on each eye, with rising pressures. These measurements are no doubt the more reliable ones, and should be considered standard values for the time being.

The time has not yet arrived to issue fresh graphs. A great number of measurements must be taken if the exact truth is to be attained, although the values found lately can hardly be very wide of those that will be final. Furthermore, a sufficient number of fresh measurements should be made with other weights.

I should like to recommend those who may undertake such measurements to try the insertion of a fine canula into the anterior chamber instead of a larger one into the vitreous. All conduction so easily goes wrong. I previously made an experiment with a canula in the anterior chamber, but unluckily overlooked the capillary attraction in the glass tube and this spoiled the experiment completely. Recently I repeated the experiment with a rather thick hypodermic needle, the point being inserted through the sclera about 2 mm. from the edge of the cornea, and carried into the anterior chamber as far as to the middle of the pupil, the opening

being turned upwards. The hollow needle was closely connected with the glass tube carrying the tap, and this again was connected by a rubber tube with the manometer; the fluid entered and left the anterior chamber easily as the manometer was moved up and down. The needle was not in the way of the tonometer foot. I have not yet had an opportunity of working in this way, but the test was so satisfactory that I recommend the method for further trial.

For the time being, those who wish to transcribe their measurements into mm. Hg., should (on Schedule II), draw up the graph for 5·5 grm. according to the values found by Priestley Smith. (Tables IX and X).

As mentioned above, these changes of Hg. values are of no importance to those who only note the deflections. At present, as before, deflections of between 3 and 6 mm. or more signify the normal intraocular pressure. The only correct method is to note what is really seen, viz., the deflection obtained with a certain weight. I record my measurements in the way advocated by Prof. Bjerrum, viz., in the form of a fraction, the weight employed over the deflection obtained.

TABLE XII.

N.B.—In each case the weight used and the deflection obtained are written as a fraction, *e.g.*, 5·5 (weight) and the approximate mercury equivalent is placed in the adjoining column — 5·5 (weight). 5 (deflection).

1. Woman, 35 years.		2. Man, 53 years.		3. Man, 75 years.	
Haemorrh. corp. vitr.	Retinitis prolif.	Cataracta senilis.	Glaucoma simplex.	Post. Synechiae.	
mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.
$\frac{5.5}{5}$ 16·75	$\frac{5.5}{5}$ 18	$\frac{5.5}{7.5}$ 13	—	$\frac{5.5}{6.5}$ 14·25	$\frac{5.5}{6.5}$ 14·25
$\frac{7.5}{8.5}$ 14·7	$\frac{7.5}{7.25}$ 18	$\frac{7.5}{10}$ 11·5	—	—	—
$\frac{10}{11.5}$ 13·5	$\frac{10}{10}$ 17	$\frac{10}{13.5}$ 12·75	$\frac{10}{0.75}$ 74	$\frac{10}{11.75}$ 12·8	$\frac{10}{11.25}$ 13·8
$\frac{15}{15.5}$ 12·5	$\frac{15}{14.}$ 15·75	$\frac{15}{17}$ 9·7	$\frac{15}{3.5}$ 77	$\frac{15}{15.5}$ 12·25	$\frac{15}{15.75}$ 12·75
$\frac{5.5}{7}$ 13·25	$\frac{5.5}{6+}$ 15·25	$\frac{5.5}{85}$ 10·7	—	$\frac{5.5}{7.25}$ 12·8	$\frac{5.5}{7.25}$ 12·8

It should be kept in mind that a given deflection does not indicate a definite pressure in mm. Hg.; it represents a range which is not insignificant, as is shown by the maxima and minima in Table VII. If we fix a deflection of 3 mm. as the limit between normal and pathological pressure, we do so just because it represents a range between the normal and the pathological. The boundary is never sharply defined; it is a range lying probably between 32 and 25 mm. Hg. A deflection of 2 mm., representing the range between 36 and 29.5 mm. Hg. may be assumed in most cases to indicate a pathological pressure.

The use of loose weights which have to be changed during the examination may appear inexpedient. Certainly it would be easier to use only one, but this would have to be considerably larger, an innovation which I consider absolutely wrong. A heavy weight means an unnecessary strain on normal eyes, and causes a depression

4.		5. Woman, 56 years.		6. Man, 75 years.	
		Cataracta.	Hypermetropi.	Glaucoma simplex.	Glaucoma Operat. Elliot.
mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.
$\frac{5.5}{8}$	11.5	$\frac{5.5}{7}$	13.25	$\frac{5.5}{5}$	18
—	—	$\frac{7.5}{8-}$	16	$\frac{7.5}{1}$	51
$\frac{10}{13.5}$	9.75	$\frac{10}{9.5}$	18.25	$\frac{10}{3}$	51
$\frac{15}{17.5}$	8.9	$\frac{15}{14+}$	15.5	$\frac{15}{7}$	47
$\frac{5.5}{9}$	9.9	$\frac{5.5}{6}$	15.2	$\frac{7.5}{1}$	51

in the cornea of 1 mm. or more, which is undesirable, and, as far as my experience goes, would not increase the reliability of the indications. My opinion is that the most reliable deflections are those from 1 mm. to 5 mm., or at the outside 10 mm. If a deflection smaller than 1 mm. is obtained, a heavier weight should be employed; and if with a heavier weight the deflection is greater than 5—6 mm., a lighter weight should be substituted.

Lastly, a heavy weight does not give exact information with

regard to eyes with normal or slightly increased pressure; it causes fluid to be pressed out of the eye, and thus reduces the pressure below its original state.

If several weights are used, the graphs should be proportioned to each other in such a manner that measurements with various weights on the same eye should yield approximately the same results. I have had a series of such measurements taken by my assistant, employing first the 5.5 grm. weight, then the 7.5 grm., 10 grm., 15 grm., and lastly the 5.5 grm. Again, the results are given in Table XII.

7. Woman 75 yrs.		8. Woman 32 yrs.		9. Woman 19 yrs.	
Cataracta incip. Both eyes.		Morb. nullus.		Morb. nullus.	
mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.
5.5 18	5.5 15.2	5.5 13.3	5.5 13.7	5.5 17.9	5.5 14.75
5	6	7	7	5+	6.75
7.5 14.7	7.5 12.2	7.5 13.5	7.5 14.7	7.5 15.75	7.5 14
8.5	9.5	9	8.5	8	8.75
10 13.9	10 12.3	10 14.4	10 16.75	10 14.6	10 14.3
11.75	12	11	10	11—	11+
15 13.2	15 10.5	15 13.3	15 15.6	15 14.4	15 13.3
15	16.5	15	14	14.5	15
5.5 14.3	5.5 13.3	5.5 12.4	5.5 13.3	5.5 15.2	5.5 13.4
6.5	7	7.5	7	6	7

What at once strikes the observer in this Table is that the values on the whole decrease as the weights increase. This might of course indicate that the graphs for the heavier weights are too low, but when we see that the 5.5 grm. weight always indicated a lower pressure at the end of the series of measurements than at the beginning, we must conclude that fluid was pressed out of the eye by the heavier weights, and that the intra-ocular pressure was really reduced thereby, except perhaps in the glaucoma cases (Nos. 2 and 5). Allowance being made for this effect the values are so close to each other that there can hardly be any considerable error in the relation between the graphs.

These measurements show that it is inadvisable to use weights that are heavier than is absolutely necessary for the production of reliable deflections of the pointer. The pressing out of fluid when

heavy weights are used is especially evident in the case of dead eyes; it proves that the eye cannot be regarded as a completely closed organ, except perhaps in cases of glaucoma.

The conditions in a living eye are in some respects similar to those obtaining in a test-drum connected with a manometer, inasmuch as the blood pressure may be compared with such an instrument. As long as the outlets of the eye are roomy and in good working order, slight variations in pressure and influx of fluid, such as must presumably take place when the action of the heart is increased, are of no importance. Even with an increased blood pressure, normal pressure may be found in the eye.

10. Man 31 yrs.		11. Woman 36 yrs.			
Morb. nul.	Mac. corn.	Morb. nullus.			
mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.	mm. Hg.
5.5	5.5	5.5	5.5	5.5	5.5
17.9	15.3	17.9	17.9	17.9	17.9
5	6	5	5	5	5
		7.5	7.5	7.5	7.5
		16	16	16	16
		8	8	8	8
10	10	10	10	10	10
16.9	14.5	16.25	16.25	16.25	16.25
10	11	10.75	10.75	10.75	10.75
15	15	15	15	15	15
17	15.5	15.5	15.5	15.5	15.5
13.5	14	14	14	14	14
5.5	5.5	5.5	5.5	5.5	5.5
16.7	12.8	12.3	12.3	14.3	14.3
5.5	7	7.5	7.5	7.5	7.5

But when the outlets grow insufficient, the fluid in the eye must be dammed up, and the intra-ocular pressure must necessarily rise. As the normal blood pressure in the central artery of the retina scarcely exceeds the normal intra-ocular pressure it would not now be sufficient to drive the blood into the eye, but as the distance between the central artery and the carotid is short, the blood pressure will increase so much that a sufficient quantity of blood will enter the eye. As the outlets of the eye grow more inefficient, the intra-ocular pressure must rise, just as when the manometer is raised, and in this manner a circulus vitiosus is established. We may assume, however, that a balance between influx and outlet may be established at any level of pressure, for a shorter or longer period.

If the pressure is driven further upwards, a point will be reached

when the intra-ocular pressure exceeds the diastolic, but is less than the systolic blood pressure. I have once seen a case in which the blood column in the central artery was flung over the edge of the papilla with each systole and disappeared during each diastole. This was before the advent of the tonometer, so that to my regret I do not know what the intraocular pressure was. At such high pressures the cornea is as a rule so dim that the interior of the eye is not visible.

If the intra-ocular pressure is still further increased, and exceeds the systolic pressure, no blood will enter the eye and the sight will be lost after a short time owing to the absolute anaemia of the retina. Such is presumably the case in the so-called glaucoma fulminans. I have not seen a genuine case of this but only one nearly similar. The sight of one eye was lost in the course of 24 hours, and that of the other was reduced in one day to counting of fingers at $1\frac{1}{2}$ m.; the pressure was $\frac{15^*}{<2}$, i.e., nearly 100 mm.

Hg. The blood pressure must have been a little higher still. The patient had afterwards an iridectomy with iridencleisis, filtration, and V 6/18.

The Standardization of the Tonometer

The testing is done at the electric works of Mr. N. Jacobsen. Once in a while a sample tonometer is sent to me to be tested, and as a rule I have been satisfied with the work. To my regret I am unable to test all tonometers personally; I have therefore thought it would be of use to point out how everyone can test his own tonometer.

For the purpose of standardization eyes are not suitable. An apparatus is needed that will always give the same results when the tonometer is applied to it. Such an apparatus we have found in the metal drum covered with a thin rubber membrane as shown in the illustration on page 202.

As already said the drum has an inside diameter of exactly 14 mm. and a volume of 2-3 cubic cm. The walls are about 2 mm. thick. The upper edge over which the membrane is stretched should slope outwards a little, and the ring which is placed over the membrane must be shaped so as to fit the rim exactly. The ring is pressed down by two screws to keep the membrane in position. Below the drum there is a tap and below this a narrow neck over which the rubber tube of the manometer is slipped. This neck should not be too short as it is to be placed in a clip on a stand. Two arms turned upwards may be screwed fast to the drum, each having a notch at the upper end; the handle of the tonometer is placed in these in order to avoid holding it in the hand whilst measuring.

*This is not a fraction; it is Schiötz's method of recording a tonometer reading. 15 means that the 15 grm. weight was used; and < 2 means that the pointer stood at less than 2 on the scale.—*Editor*.

I have found the most suitable membrane to be thin sheet rubber; I chose a grey "preservative" rubber, used in women's dresses, which varies very little in thickness, and which I presume is obtainable everywhere. Its thickness may be determined by measuring two cover-glasses first with, and then without, the rubber sheet between them: That which I have used is 0.133 mm. in thickness. Fortunately a slight variation in the thickness does not seem to influence the measurement materially.

In order to exclude air bubbles the membrane may be fastened on to the drum under water, or it may be fastened first and then the drum may be filled with water by means of a syringe with a long nozzle. The drum is then connected with the rubber tube and fastened by screws to a stand, as shown in the illustration.

For measurements with open communication between drum and manometer the tonometer may be left standing in the arms already mentioned, and the deflections of the pointer may be read as the manometer is raised or lowered. It is often advisable to tap the table slightly in order to secure the correct position of the pointer. For measurements with the connection closed the tonometer must be lifted completely off the membrane before the tap is closed.

In Table XIII. I give the measurements taken on a single rubber membrane which would not sustain water pressure of over 80 cm., and also on a double rubber membrane (0.133×2) which sustained a pressure of 120 cm., the highest pressure I employed. These measurements were made on the standard tonometer; graphs may be drawn up from them and other tonometers may be tested by means of them.

TABLE XIII.

SINGLE GREY "SHIELD" RUBBER MEMBRANE, 0.133 MM. THICK.
DEFLECTIONS OF POINTER IN MM.

Pressure in cm. H ₂ O.	5.5 gm.		7.5 gm.		10 gm.		15 gm.	
	Open.	Closed.	Open.	Closed.	Open.	Closed.	Open.	Closed.
5	...	...	—	14	—	—	—	—
10	...	...	—	10	—	—	—	—
15	...	...	—	8	—	—	—	—
20	...	...	16.5	5.8	—	14.3	—	22
30	...	...	8	3.4	—	10.1	—	17.3
40	...	...	4.3	2	88.5	4.1	15	7.3
50	...	...	2.55	1.1	5.5	2.9	10.2	5.3
60	...	...	1.5	0.65	3.7	2	7.1	4
70	...	...	0.8	0.1	2.5	1.3	5	3
80	...	...	0.3	0	1.7	0.9	3.8	2.3
90	...	...	0	—	—	—	—	—

Strongly over-distended.

Before undertaking any measurements it should be ascertained that the pointer of the tonometer is correctly placed, i.e., that it points to the first line, the zero line, when placed firmly on the "model." I presume that everyone has noticed the facet or small flat area in the convex surface of the model. I have given the reason for this in an earlier article ("Tonometrie," *Arch. f. Augenheilk.*, Vol. LXII, Part iv, p. 339, 1909. Ueber die Justirung, etc.)

DOUBLE GREY "SHIELD" RUBBER 2.133 MM. THICK.
DEFLECTIONS OF POINTER IN MM.

Pressure in cm. H ₂ O.	5.5 gm.		7.5 gm.		10 gm.		15 gm.	
	Open.	Closed.	Open.	Closed.	Open.	Closed.	Open.	Closed.
5	...	...	—	11	—	—	—	—
10	...	...	—	8	—	—	—	—
20	...	...	14	5	21.5	7.8	—	17
30	...	...	6.5	3	12.1	5.3	—	13.5
40	...	...	3.9	2	7.5	3.7	13	6.1
50	...	...	2.3	1.2	5	2.7	8.9	4.8
60	...	...	1.5	0.7+	3.4	2—	6.6	3.7
70	...	...	0.9	0.3	2.4	1.2	4.8	2.9
80	...	...	0.4	0	1.7	0.9	3.6	2+
90	...	...	0+	—	1.1	0.6	2.9	1.5
100	...	...	—	—	0.7	0.25	2+	1.1
110	...	...	—	—	0.4	0	1.5	0.9
120	...	...	—	—	0+	—	1.1	0.5
							3.8	2.6

The "model" belonging to the standard tonometer, with which all measurements for the graphs were made, was found to have a slightly longer radius of curvature than the corresponding concavity of the foot, the difference being such as to cause the index to point one millimetre beyond the zero line when an exactly fitting model was used.*

This fault, if such it be, proved advantageous, because it excluded the last millimetre of the scale. This last millimetre was a somewhat dead area, for the manometer had to be raised to a great height in order to move the pointer quite to the zero line, at least this was so when measuring on a rubber membrane.

If, on testing a tonometer any considerable differences are found between the deflections given by the tonometer and the graphs constructed from Table XIII, their importance will depend on their position on the scale. If they occur between 12 mm. and 20 mm., as often happens, they are of no consequence. In the neighbourhood

*An excellent model is found in the 30 mm. steel balls made by Nordisk Kuglelager A/S (N.K.A.), which I presume are to be had everywhere. These balls are made with such exactitude that with the ophthalmometer the same adjustment is found throughout the surface of the ball.

of 3 mm., on the contrary, they are inadmissible, for, as we have seen, deflections of 3 mm. obtained with the 5.5 grm. weight are of special importance. If an error is found in this region, an attempt may be made to correct it by a slight adjustment of the pointer, i.e., by bending it a little beyond or a little within the zero line while the tonometer rests on the model. As a rule, the error will be slight enough to allow of rectification in this way; if, however, a slight bending proves insufficient, the loose weights must be made heavier or lighter as the case may be.

The reason that the deflections between 12 and 20 mm. need not necessarily be accurate is that such deflections, when obtained with one of the heavier weights, should be rejected; even when the deflections reach to 5 or 6 mm. a lighter weight should be used. On the other hand, if deflections of more than 12 mm. occur with the 5.5 grm. weight, they fall within a part of the graph where the slope is so slight that a difference of a couple of millimetres is of no importance, e.g., a deflection of 12 mm. signifies a pressure of 6 mm. Hg., and one of 14 mm. a pressure of 4.5 mm. Hg., a difference which has no practical significance.

Two New Tonometers

Finally, I desire to mention two tonometers made in America.

One is Gradle's tonometer. It is the Schiötz tonometer in every respect, but with a few "improvements" the nature of which is such that I do not consider it worth while to discuss them in detail.

The other is McLean's tonometer, a very beautiful instrument, but, to tell the truth, I cannot in this case either find any real difference between it and the Schiötz. The design and the principle are similar, though the index is made to point downwards instead of upwards. A few other slight alterations have been made, and these undoubtedly will influence the measurements, so that it will probably give results a little different from those obtained by the Schiötz tonometer.

Dr. McLean, in his lecture (Oxford Ophthalmological Congress, July 10, 1919) on "Further Experimental Studies in Intra-ocular Pressure and Tonometry," put forward the following objections to the Schiötz tonometer.

(1) The scale is placed too high; it is impossible to note the deflections, and at the same time to control the position of the tonometer on the cornea. I agree, but even with the McLean tonometer it is necessary to look at the scale, and I do not think it matters greatly whether I lift my eyes 5 cm. or 15 cm. from the foot. On the other hand, I consider it a great disadvantage in the McLean tonometer, that by reason of the position of the pointer the plunger cannot be taken out to be cleaned.

(2) One must refer to a graph for the translation of deflections into mm. Hg. It is true that the method is cumbersome, but it never occurs to me, nor, I hope, to most of my colleagues, to translate deflection values into mm. Hg. for everyday purposes. As stated above, only the weight and the deflections should be noted.

(3) The fine lines and squares on the graph schedule are difficult to read. This has nothing to do with the tonometer. Those who use the graphs very often should have them drawn out on a large scale and hung on the wall.

(4) The changing of the weights is troublesome. I do not deny that it means a little loss of time, but so far it has not happened to me that any patient has become nervous on that account. I have already given my reasons for employing several weights and will not repeat them here. The difficulty will be overcome if the new model proves satisfactory.

(5) Capillary action of fluid mounting between the plunger and the cylinder may vitiate the measurement. Such action can only take place near the lower end and only to a height of 1 mm. Higher up there is a distance of at least 0.5 mm. between the plunger and the cylinder walls, and no capillary action can take effect. I estimate the amount of fluid which might be raised by capillary force at about 0.0095 grm., a quantity which may safely be regarded as negligible. As a rule the tonometer is not used on eyes so wet that fluid is likely to be sucked up. Dr. McLean leaves an open space between the plunger and the cylinder right down to the under surface of the foot part. This may be well enough, but the reduction of the area of the foot will not fail to influence the measurements, as already shown.

McLean's tonometer subjects all eyes to the pressure of a considerable weight, viz., 25 grm., of which 12-15 grm. falls on the plunger. For most eyes this weight is unnecessarily heavy, more than 10 grm. being needed only in very rare cases.

For reasons already given, I consider it undesirable to graduate the scale in mm. Hg., as in the McLean tonometer.

That Dr. McLean found the values obtained with the McLean and Schiötz tonometers to differ considerably is due, I think, in the first place to the fact that the Hg. values for the Schiötz are too low, and, secondly, in some degree to differences in the relative weights of the various parts of the instruments and other differences. The tonometer is a very sensitive instrument, and the slightest alteration in any detail is likely to influence the deflections. For example, I have learnt recently that the lower end of the plunger in the McLean tonometer is convex. I have already shown that the shape of the plunger has an important influence on the deflections.

When the results of Dr. McLean's measurements (BRITISH

JOURNAL OF OPHTHALMOLOGY, Sept., 1919, p. 394) are drawn up graphically, the manometric pressures being placed on the ordinates and the Schiötz values in mm. Hg. on the abscissa, the 15 grm. values yield a nearly straight line, from 30 mm. Hg. up to 90 mm. Hg.; here, however, there is a leap, and then the line goes on straight from 100 mm. Hg. to 120 mm. Hg. The straightness of this line proves the instrument to be reliable. There is no better

TABLE XIV.

McLean. mm. Hg.	Schiötz. mm. Hg.		McLean. mm. Hg.	Schiötz. mm. Hg.	
18	...	10	...	34	...
				21	...
20	...	11.5	...	43	...
				29.7	...
20-21	...	13	...	42	...
				43	...
29	...	15.5	...	about 52	...
				43	...
31	...	16.5	...	65	...
				43	...
29	...	18	...	70-75	...
				62	...
30	...	18	...	100	...
				86	...
32	...	18	...	110	...
				83	...
33	...	19.5	...	120	...
				90	...

test of the correct working of a tonometer than a graph. The "leap" hardly signifies a mistake, but rather some irregularity in the vitreous or the canula.

The line given by the other weights ought to have been straight, and all should unite in one straight line, but such exactitude is too much to expect. Where they are not straight the faults are not due to alteration of the weights, as that can have no influence in this respect; it must be due to inexact measurement or to irregularity in the vitreous or canula.

The 15 grm. graph appears to be too high, i.e., to give somewhat too low values. The values for the other three weights are so well mixed up with each other that their mutual position may be assumed as fairly correct.

When I had the McLean tonometer I was unfortunately so busy fitting up and moving into the clinic of our large new hospital, that I only obtained, and that mainly by the work of my assistant, a few comparative measurements. These are printed in Table XIV. The values can hardly be compared for they lie differently on the scale, but the instrument does not appear to offer any real improvement as regards reliability of measurement. The McLean tonometer is a Schiötz tonometer partly turned upside down, and as it is similar to the older instrument both in principle and in build it should measure as well, but nothing has been added which could lead us to expect it to measure better.

The aim of all tonometer workers should be to use instruments giving values which may be compared, and to agree on the principles on which such work should be based. A tonometer should be like a thermometer (Elliot), inasmuch as when applied to a test apparatus it should give invariable results.

In conclusion, I beg to express my gratitude to Mr. Priestley Smith for his exposition of the Schiötz tonometer, both in his work "On Tonometric Values," and in his letter replying to Col. Elliot's statements. I fully agree with his conclusion that "It is not proved, and it is not likely that the instrument errs to the extent that McLean's experiments suggest."

PRACTICAL SYMPATHY FOR THE BLINDED

BY

CAPTAIN FRANCIS P. PEIRSON-WEBBER.

True Appreciation

I write as a blinded man, to help the ophthalmic surgeon to have a nice appreciation of the situation from a blinded point of view, so that advice may be given with such practical sympathy that the natural despondency, which falls so heavily at the outset of blindness, may be brightened by helpful recommendations, and introductions, given with quiet assurance that carries conviction in such a manner as to create hope, desire, and determination to make the most of life, despite the handicap which exists.

Lectures in Practical Sympathy

It would be well if the Ophthalmological Society could arrange a course of lectures in Practical Sympathy, to be given throughout the year, so that the sighted friends and sympathisers of the blinded may acquire just that nice knowledge of daily difficulties which so often occur through their ignorance of the true situation. If a register could be compiled of nurses, companions, tutors, and