Brit. J. Ophthal. (1955) **39**, 368.

CALIBRATION OF TONOMETERS*

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THE steps which led to the current attempt to introduce standardized tonometers into the United Kingdom have already been described (Jackson, 1953). The present paper sets out the results of an examination of the possible methods of calibrating " non-standard " instruments to provide their owners with fresh calibration curves to replace those already in their possession, thus avoiding the necessity of scrapping many instruments which are still in an otherwise serviceable condition.

Since manufacturers have, until recently, lacked guidance from the profession on the desirability of adhering to rigid standards in the production of these instruments, many tonometers have been marketed often conforming to the original pattern in little but appearance. Many workers have noticed these discrepancies, and the experience of Friedenwald (1937), in examining a number of Schiötz instruments, is typical. In none of them was the weight of the plunger, with the lever arm resting on it, within 0·5 g. of the standard, and in none was the weight of the tonometer, less plunger and lever arm, within 1 g. of the supposed weight. My own experience is similar. Three Schiötz X-tonometers have been compared with one of the original instruments, which was made in Oslo and certified by Schiötz himself. All three show variation, both from the original and from one another (Table I). Yet all three came from the workshop of a reputable

TABLE I

PHYSICAL CHARACTERISTICS OF THREE X-TONOMETERS AND OF A STANDARD X-TONOMETER (SCHIÖTZ, OSLO)

Measurements	X-tonometers 1	X-tonometers 2	X-tonometers 3	Schiötz Oslo
Footplate				
Diameter (mm.)	10	10	10	10
Curvature (mm.)	12	12	12	15
Plunger				
Diameter (mm.)	3·15	3·15	3·15	3·0
Weight of plunger mechanism (g.)	5·0	5·3	5·5	5·3
Weight of entire Instrument (without Handle) (g.)	18·5	17·5	18	16

In addition, Schiötz specified that the plunger tip should be hemispherical. The instruments examined did not fulfil this requirement.

***Received for publication January 7, 1955.**

†In receipt of a grant from, and working under the auspices of, the W. H. Ross Foundation (Scotland) for the Study of the Prevention of Blindness.

manufacturer, and all three were issued with copies of the Schiötz graph. It is understandable that unanimity of readings, under such conditions, is unlikely.

Possible Methods of Calibration

(1) Human eyes, living.
(2) Human eyes, cannulated.
(3) Rubber membrane manometers.
(4) Detailed physical examination of instruments and analysis of effect of various instrumental defects on tonometer readings.

(1) Human Eyes, Living.—The usual teaching is that the normal intra-ocular pressure is about 25 mm. Hg, but there is a tendency to regard the normal range of pressure as being quite small. Fig. 1 shows the distribution of the readings in a series of 377 apparently normal eyes. These figures were obtained with an American Standard Schiötz tonometer, using 7·5 g. on the plunger. The patients were those attending an out-patient department for some minor procedure, mostly for the removal of corneal foreign bodies. The average pressure is about 24 mm. Hg, and the range from 10 to 40. This curve agrees with a similar one published by Friedenwald (1937). Very low figures are essentially meaningless, but it is worth stressing the little appreciated fact that of every hundred eyes showing no clinical evidence of disease, ten will give readings above 30 mm. Hg (Schiötz) and two or three above 35 mm. Hg.

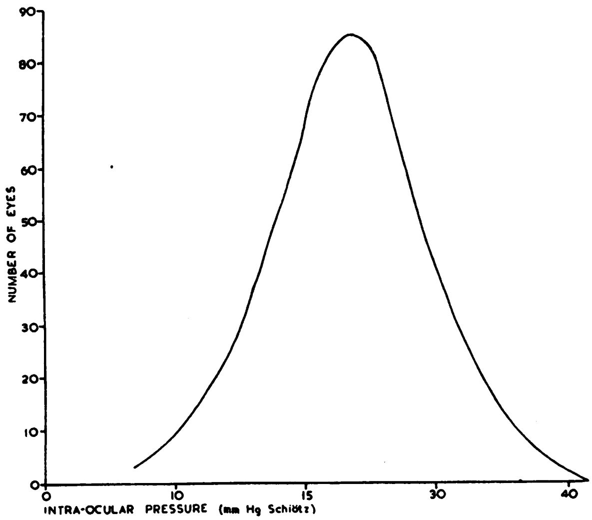

FIG. 1.—Distribution of intra-ocular pressure in 377 normal eyes. Standard Schiötz tonometer, 7·5-g. load.

For any tonometer working on the Schiötz principle the shape of the distribution curve can be assumed to be the same; though it will shift to right or left according to the behaviour of the particular instrument. It would be possible, therefore, to construct a fresh calibration curve for any tonometer by a statistical method. If the owner of a " non-standard " instrument were to take a series of readings from normal eyes, the results could be referred to a normal figure of 25 mm. Hg and a new Conversion Table constructed. The results would be increasingly accurate the larger the number of readings used.

(2) **Human Eyes, Cannulated.**—Using excised cannulated eyes, in a series of experiments lasting many years, Schiötz calibrated his tonometer, and so established the mechanical details of its construction. It would hardly be practicable to adapt this method to the problem of calibrating a large number of differing instruments. For each test a number of fresh human eyes would be required, in order to reduce the influence of the variable factor of ocular rigidity.

(3) **Rubber Membrane Manometers.**—In view of the recent suggestion by Pollak and others (1952), working in Dublin, that rubber membranes could be used for calibration, an attempt has been made to reassess the position; Prof. Pollak has been kind enough to provide me with a replica of his own manometer which has been used in this work.

The work of Friedenwald (1937) has made it clear that the reading obtained when a tonometer rests on an eye depends on a number of factors, one of which is the intra-ocular pressure. The other factors, summed up in the term " ocular rigidity ", include the resistance of the ocular coats to deformation and stretching, and the resistance of the vascular bed of the eye to the expulsion of fluid by the massaging effect of the tonometer. The effect of these additional factors cannot be reproduced in a solid chamber covered by a rubber membrane and connected to a manometer.

The majority of workers, including Schiötz himself and Posner (1943), have used rubber membranes to check the performance of tonometers of identical physical characteristics; they are agreed that it is for such a purpose alone that the use of these manometers is justified.

A comparison was made between the behaviour of a standard American tonometer on the drum of the manometer with that of the same instrument on the eye, the curves for the readings on the eye being those of Schiötz himself, slightly modified as a result of Friedenwald's work on ocular rigidity. Next an attempt was made to recalibrate a tonometer on the rubber drum.

In both sets of experiments the standard Schiötz curves were used to check the results obtained.

(*a*) *Behaviour of Instrument upon the Drum.*—All readings were taken with a standard Schiötz tonometer (No. 5064, certified correct by the American testing laboratory). Under experimental conditions this instrument can be read to ¼ division on the scale, and the average of several readings is taken for each point.

Fig. 2 (opposite) shows the results obtained by plotting tonometer readings against the pressure within the drum (mm. Hg). All three curves show a similar form which differs from that of the standard Schiötz curves (Fig. 3, opposite).

(*b*) *Calibration of Unknown Instrument.*—The Dublin workers have indicated that any tonometer can be calibrated against a standard instrument on a manometer. The fact that the shape of the curves obtained on a manometer differs from that of the standard curves may not therefore be of importance, provided that the relationship between the readings at the various weights and pressures remains the same, as in the case of the eye. (For example, if the standard instrument reads " 1 " on the drum and the unknown instrument reads " 5 " at the same pressure, then the unknown instrument should read " 5 " on an eye if the standard instrument reads " 1 " on that eye).

The two sets of curves (Figs 2 and 3) represent respectively the ascertained behaviour of the instrument on the drum and its accepted behaviour on the eye.

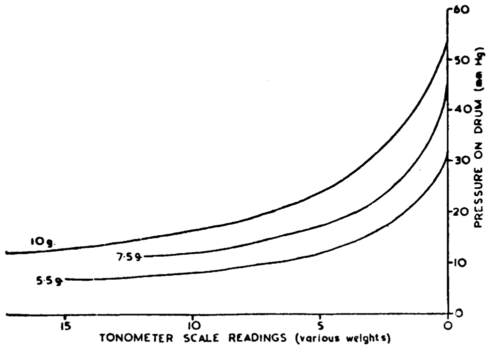

FIG. 2.—Standard tonometer. Relationship between scale reading and pressure on rubber membrane manometer. 5·5, 7·5, and 10-g. loads.

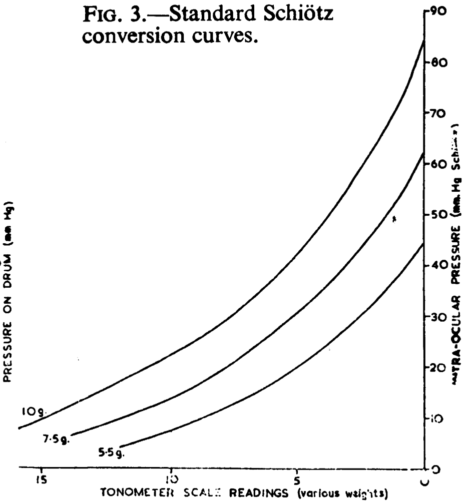

FIG. 3.—Standard Schiötz conversion curves.

TABLE II

RELATIONSHIP BETWEEN READINGS AT DIFFERENT WEIGHTS, SCHIÖTZ AND DRUM COMPARED

5·5-g. Load Reading	7·5-g. Load Reading		10-g. Load Reading	
	Schiötz	Drum	Schiötz	Drum
1	3·5	2·25	6·0	4·75
2	4·5	4·5	7·25	7·5
3	5·75	6·5	8·5	10·5
4	7·0	8·0	9·75	13·0
5	8·0	10·0	10·75	15·0
6	9·25	11·5	12·0	16·5
7	10·0	—	13·0	—
8	11·0	—	13·75	—
9	12·0	—	14·75	—
10	13·0	—	15·75	—
11	14·0	—	—	—

From these curves can be read off the relationships between the readings of the various plunger loads at different levels of pressure, either in the manometer or in the eye. These figures are set out in Table II. Fig. 4 (overleaf) shows the result of plotting the relationship between the readings with the 5·5-g. load and those with the 10-g. load, both derived from their behaviour on the drum and from the standard Schiötz curves. These readings disclose wide discrepancies between the behaviour of an instrument on the drum and its known behaviour on the eye.

As a further step in the assessment of the membrane manometer as a possible means of recalibrating tonometers, a practical test was adopted, again using the American standard instrument.

In any recalibration experiment of this type, it has been found difficult to assess the accuracy of the results. To check the results clinically would be possible, but a large number of readings would be necessary to ensure accuracy. The availability of a standard tonometer having variable weights presents a possible solution.

It must be assumed that the Schiötz curves are correct, for they were based on detailed experimental work, and were later supported by mathematical analysis of the factors involved by Friedenwald (1937).

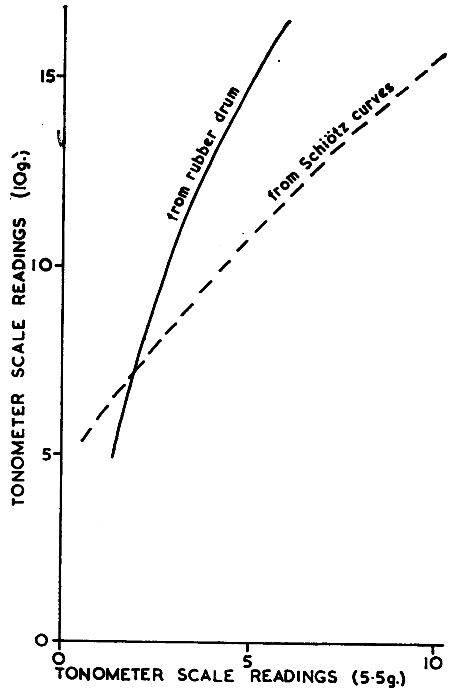

FIG. 4.—Relationship between scale readings at different weights. Curve from manometer compared with standard Schiötz curve.

For reasons which have already been discussed, to use a membrane manometer for calibration purposes, the relationship between the readings of two tonometers should be the same on the drum as on the eye. The maintenance of this relationship would allow the known performance of the first tonometer, having a reliable conversion curve, to be transcribed to that of the second, so permitting the construction of a conversion curve for the second, or " non-standard ", instrument.

With the American standard tonometer, a series of readings were taken on the drum, with gradually increasing pressure in the chamber. At each level of pressure readings were taken with two different weights on the plunger, 5·5 and 10-g.

Using the standard Schiötz conversion curve for the 5·5-g. load, the readings at this load were converted into mm. Hg (Schiötz) of intra-ocular pressure. It was then possible to draw a theoretical conversion curve for the 10-g. load, using the scale readings obtained on the drum. In effect, the 5·5-g. load with its conversion curve was being used as the standard, while the 10-g. load represented the " unknown " instrument whose calibration was desired.

The calibration curve for the 10-g. load obtained in this manner, is shown in Fig. 5 where it is compared

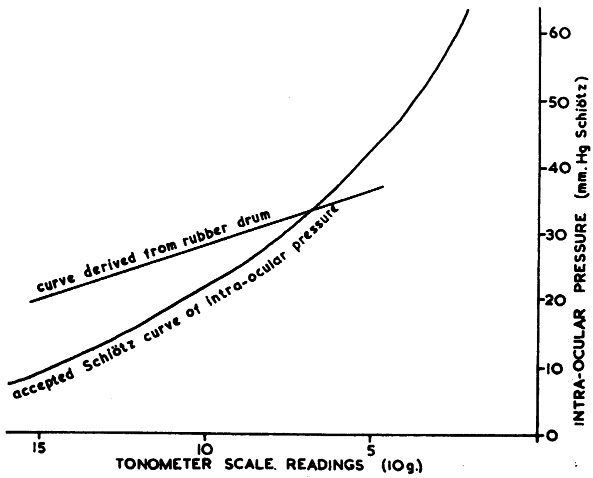

FIG. 5.—Calibration of tonometer with 10-g. load on membrane manometer, using 5·5-g. load as standard. Results compared with Schiötz graph.

with the accepted Schiötz curve. The two curves are markedly dis-similar.

These two experiments show that the relationship between the scale readings of the various weights, as obtained on the drum, are not the same as those obtained on the eye, and therefore suggest that a comparison between the results obtained on the drum and on the eye is misleading.

(4) Analysis of the Effect of Various Instrumental Defects on Tonometer Readings.—When large numbers of tonometers of varying construction have been examined, as they have been in the testing stations in the United States, it is seen that the various deviations from specification occur at differing frequencies and that a single deviation may occur as an isolated defect in certain instruments. When this occurs it is possible to assess the effect of this particular defect on the behaviour of the instrument. Among the common defects found in the examination of tonometers there may be an incorrect total weight, wrongly curved test-block or foot-plate, or a faulty relationship between the length of the pointer and that of the hammer. It is this last which represents the " magnification " of the system. In a properly constructed instrument, each millimetre of movement of the pointer is produced by a 0·05-mm. movement of the plunger.

As a result of the accumulation of several years' experience, American workers have been able to assess the influence that the presence of the commoner mechanical deviations may be expected to have on tonometer readings. After detailed physical examination of an instrument, therefore, mathematical correction factors can be applied, and a fresh conversion curve prepared. In this way, numbers of " non-standard " instruments have been salvaged to give readings approaching those of the reference standard instrument. These correction factors have been published by the American Academy of Ophthalmology and Otolaryngology in the "Decennial Report on the Standardization of Tonometers" (1954); their possible application to the problem of variations among tonometers in Great Britain is to be studied.

Summary and Conclusions

The possible methods of recalibrating inaccurate Schiötz tonometers are described. It is considered that a method involving detailed physical examination of the instruments, with application of mathematical correction factors to the standard conversion chart, is the most likely to be valuable; although a method based on a statistical analysis of the results of readings taken from a number of normal eyes may be useful. A rubber membrane manometer does not seem to offer a simple method of recalibrating an unknown tonometer.

The problem is one of some complexity and a speedy solution is unlikely.

Dr. F. W. Campbell has helped me with the analysis and arrangement of some of the results published herein. For this help I am grateful.

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