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THE WOLFE SCLERAL TONOMETER: AN EVALUATION

BY

JOHN H. CARTER M., O. D.

Bloomington, U. S. A.

Introduction:

It is probable that the selection of the cornea as the popular site of tonometer application was based upon its obvious accessibility and upon the relative thinness of its epithelial coat. Further, it may have been assumed that the cornea provided more favorable physical characteristics than the sclera.

The cornea as a site for tonometer application is not, however, without its disadvantages. Certain pathological states affecting the anterior refracting surface may make tension measurement difficult, unreliable, or hazardous. Minor corneal injuries are not infrequent. Apprehension may bring about spasm of the palpebral portion of the orbicularis muscle causing pressure to be exerted against the eyeball thereby giving rise to spurious estimates as to the magnitude of the original pressure. Further, the associated use of topical anesthesia may make the corneal epithelium especially susceptible to damage.

Scleral tonometry using the Wolfe instrument has recently aroused considerable interest in certain circles and several excellent reporte ([1, 2, 3]) of the results of clinical study have appeared in the literature.

It has been the purpose of the present investigation to analyze the physical and mechanical characteristics of the Wolfe instrument as well its perfomance on pressure controlled animal eyes.

The Wolfe Scleral Tonometer appears to be a variant of the French Bailliart Tonometer (see Figure 1). The instrument presently available, the Wolfe Model "C", is manufactured by the Chicago Dial Indicator Company under the auspices of the Departament of Clinical Research of the Illinois College of Optometry.

Hirsch ([2]) has reported that the average pressure determined by the Wolfe instrument is similar to that obtained by the use of the Schiötz and further that the ranges of the two instruments appear to be very nearly identical.

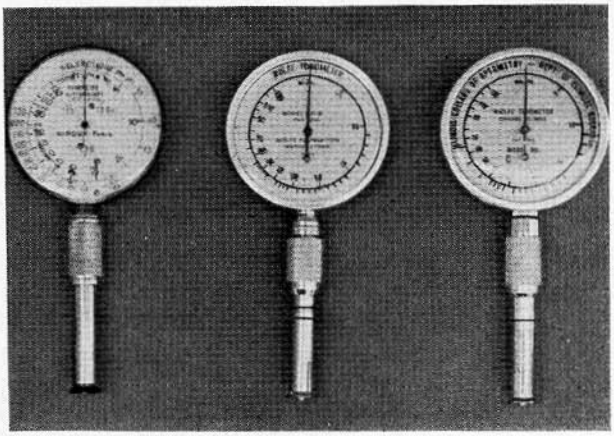


Fig. 1. The Bailliart Tonometer (left) together with the Wolfe Model B (center) and the Wolfe Model C (right).

In spite of this similarity, scleral tonometry using the Wolfe instrument appears to differ markedly from corneal tonometry in at least two respects. First, it has been reported that the initial reading taken with the Wolfe instrument is frequetly spurious thus necessitating that readings be taken in multiple and the first reading be discarded. Second, a bimodality appears to be characteristic of the Wolfe distribution curve with the secondary peak occurring somewhere between twenty-five and thirty millimeters of mercury.

PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE WOLFE TONOMETER:

Apparently the dial of the Wolfe Scleral Tonometer has been taken from the Bailliart instrument (Figure 2). Note that the French instrument shows a scleral

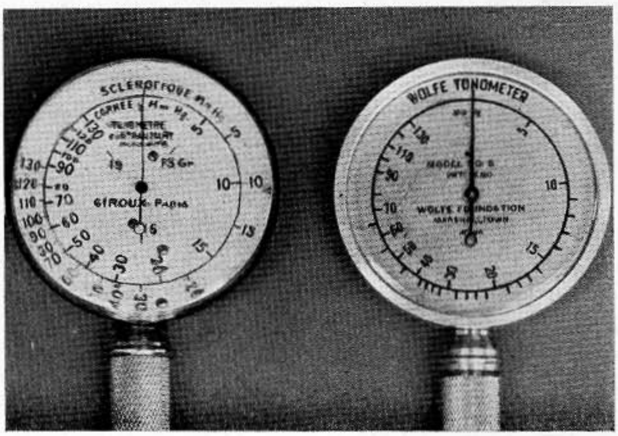


Fig. 2. The faces of the Bailliart and the Wolfe tonometers. Note the identity, even to irregular spacing, between the scale of the Wolfe instrument and the Bailliart corneal scale.

and a corneal scale and it is the corneal rather than the scleral scale which has been used in the Wolfe Scleral Tonometer. The scale is not linear and has some irregularities as is shown in Figure 3, in which figure the Wolfe scale reading in millimeters of mercury is plotted against the needle deviation in arc degrees.

To check whether or not the irregularity of the Wolfe dial scale was in compensation for a non-linear gear mechanism (Figure 4), the depth of scleral indentation recorded in millimeters by means of specially constructed micrometer (Figure 5), was plotted against the angle of needle rotation (Figure 6). Seventy millimeters of mercury on the scale was taken as the point of zero indentation. It is apparent that the mechanism does not deviate by any significat amout from linearity except for scleral indentations of less than approximately 0.2 mms. (four Schiötz units).

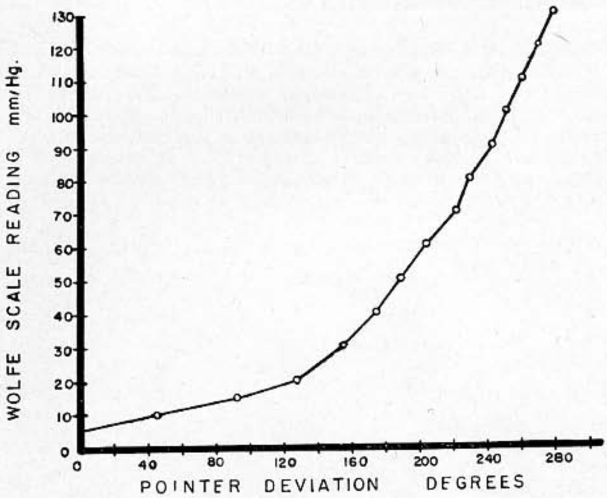


Fig. 3. The Wolfe scale reading in millimeters of mercury plotted against the angular value of the needle rotation in degrees of arc.

A calibration curve identical in form to that of the Schiötz instrument would scarcely be expectated since, in a spring-loaded instrument, the plunger load is a function of the indicator position. Nevertheless, it was decided to plot the depth of scleral indentation (Schiötz units) against the pressure designation of the Wolfe instrument (mms. Hg.) (Figure 7). Since the curve is not like the Schiötz calibration curve, it is apparent that the original scale was not taken from the Schiötz.

The effects upon the clinical estimate of the intra-ocular pressure of an unusually high ocular rigidity are minimized when a tonometric device is used to measure intra-ocular pressures above its critical pressure. (4[a]) The critical pressure o fa Wolfe Model "C" Tonometer was calculated and found to be in excess

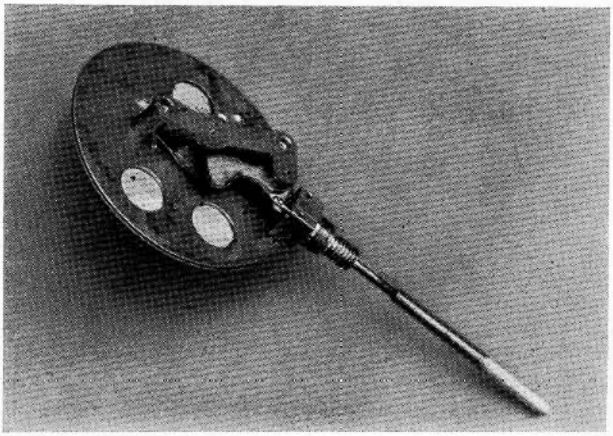
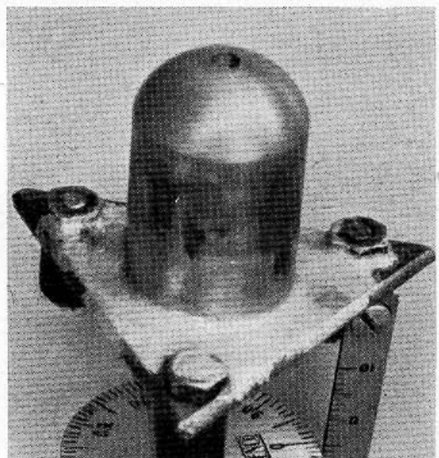


Fig. 4. The mechanism of the Wolfe Model C tonometer. The shaft within the stem of the instrument is attached rigidly to the plunger at one end and with one component of the gear mechanism at the other end. The upper end of the shaft describes an arc as the plunger is activated. This motion is permitted by a loose fit of the plunger the tonometer footplate. Obviously, plunger motion is not purely vertical but a slight rocking action of the plunger end is permitted to occur. A spring within the instrument provides the plunger load although the weight of the plunger and shaft must contribute to the load when the instrument is used in a vertical position.

Fig. 5. A micrometer constructed for the purpose of determining the magnification characteristics of the Wolfe Tonometer. The central zone of the upper portion of the micrometer has a fifteen millimeter radius of curvature. A hole drilled in the center permits entry of the tonometer plunger where it contacts an internal shaft which in turn communicates with the screw mechanism of a modified spherometer. Plunger movement can be measured to an accuracy of 0.01 millimeter.



of sixty nine millimeters of mercury due to the extreme amount of pressure with which this instrument is applied to the eye.

Even though the range of the dial of the Wolfe implies the greatest range of readings found in any tonometric device, being calibrated from 5 to 130 mm. Hg., seventy millimeters of mercury must be considered to be the upper functional limit of the instrumet because the plunger end is flush with the footplate at this level and hence no longer indents the sclera.

The Wolfe is designed to permit meassurement of the intra-ocular pressure with the patient either seated or reclining. Increased tension on the spring with in the handle partially compensates for the lack of gravit, when the instrument is used in the horizontal position.

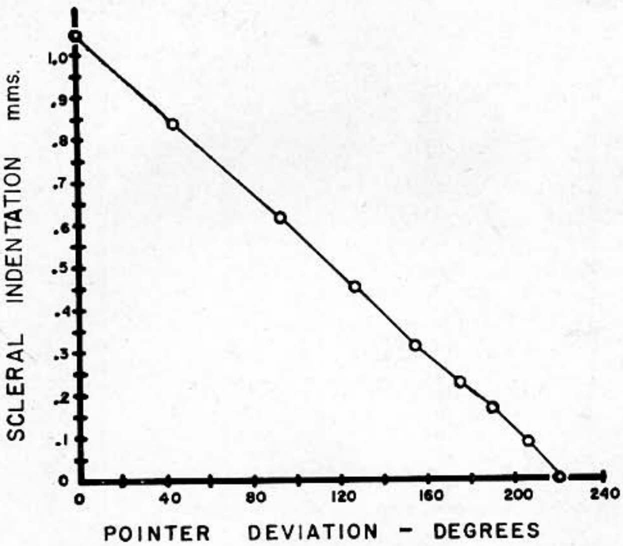


Fig. 6. The distance in millimeters by which the plunger end extends through the footplate plotted against the corresponding angular movement of the indicator expressed in degrees of arc.

Unlike the case of the Schiötz instrument in which the plunger load assumes essentially a constant value irrespective of the indicator position, the plunger load of the Wolfe and Bailliart instruments varies as a function of the Scale reading. The Bailliart dial has been provided with three check-points which may be used to periodically test the precision of the plunger spring tension. A knurled nut within the instrument stem permits alteration of the spring tension should this be required.

Although the Wolfe Model "B" is provided with a mechanism for spring tension adjustment similar to that found in the Bailliart, no scale check points are provided. In the Wolfe Model "C" no provision of adjustment of spring tension nor check points on the dial are found.

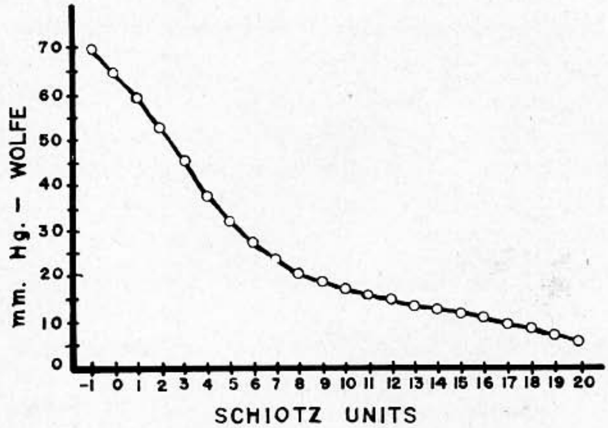


Fig. 7. The Wolfe scale reading in millimeters of mercury plotted against the plunger extension in Schiötz units as measured by micrometer. One Schiötz unit is equivalent to 0.05 millimeter.

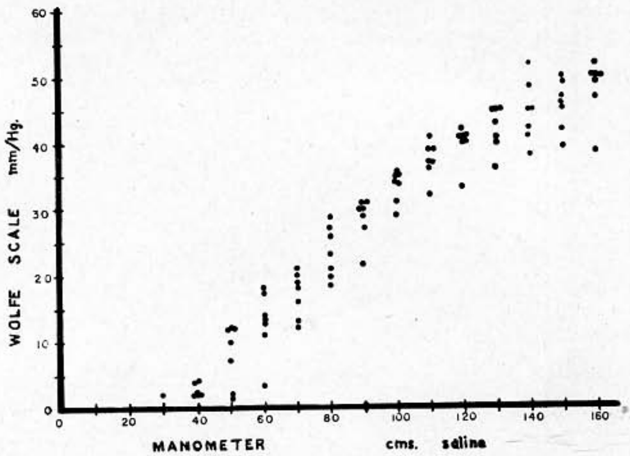


Fig. 8. The Wolfe scale reading in millimeters of mercury plotted against the manometric reading in centimeters of saline. Data was obtain using pig eyes and an open stopcock technique.

Table I ilustrates several differences between the Wolfe and Bailliart instruments.

TABLE I

Several Differences Between the Wolfe and the Bailliart Tonometers

	Bailliart	*Wolfe "B"*	*Wolfe "C"*
Calibration Check Points	YES	NO	NO
Non-Adjustable Hair Spring in Head	NO	YES	YES
Adjustable Compression Spring in Shaft	YES	YES	NO
Scleral Tension Scale	YES	YES*	YES*
Corneal Tension Scale	YES	NO	NO

* Identical to the corneal scale of the Bailliart Instrument.

PRECISION OF STANDARDIZATION OF THE WOLFE TONOMETER:

It is advantageous for all tonometers of one type to be standardized so that the reading taken upon an eye of given tension with one instrument will be identical to the reading which would have been obtained had a different instrument been used. Kronfeld has demostrated that one satisfactory mode of tonometer standardized consists of establishing fixed values for each of the essential variables of a tonometric instrument. [4b] An instrument will give readings consistant with other tonometric instruments of like type only if the physical characteristics are identical.

As only one Wolfe "B" was at hand for study and as many variations between the "B" an "C" instruments were apparent, it was felt that there would be little to gain by reporting the physical characteristics of the solitary "B" model.

The physical characteristics of three Wolfe "C" instruments, all in apparently good condition, were measured. All of these instruments had been in active use in the Indiana University Optometry Clinic. None had been claimed by the manufacturer to be a standard instrument.

Table II shows the measured values for each of the three Wolfe instruments under test. Manufacturer's specifications were included when available.

TABLE II

Physical Characteristics — Wolfe "C" Tonometer*

Characteristic:	Mode of Measurement:	Finding:
1. *Overall weight (Handle included)*	Measured with a triple beam balance with a sensitivity of 0.01 gram.	Wolfe Nº 1: 53.15 gm. Nº 2: 52.91 gm. Nº 3: 52.81 gm. **Standard: 42.5 gm.
2. *Instrument weight less plunger weight plus spring tension when handle is depressed to red line*	Plunger removed from instrument. Instrument supported by means of a laboratory jack attached to its handle. Instrument lowered foot first onto the pan of a triple beam balance. Height of laboratory jack and position of balance weights altered until end pointer of balance read zero at the same time that the instrument handle was depressed to the red line on the sleeve.	Wolfe Nº 1: 64.5 gm. Nº 2: 63.1 gm. Nº 3: 62.4 gm.
3. *Instrument weight less plunger weight plus spring tension when handle is depressed to black line*	Measurement made as in 2 above except that the black rather than the red sleeve indication was utilized.	Wolfe Nº 1: 70.7 gm. Nº 2: 69.8 gm. Nº 3: 70.6 gm.

* All Measurements made at a temperature of twenty seven degrees centigrade.

** It has been assumed that the manufacturer's specification for "overall weight" includes the weight of the instrument handle. If it does not, the magnitude of the discrepancy between specified weight and measured weight may be considerably reduced. The writer was unable to remove the instrument handle and hence handle weight is not known.

Characteristic:	Mode of Measurement:	Finding:
4. *Available spring tension to compensate for effective loss of instrument weight when instrument is used with patient in a seated position*	Item Nº 3 above less item Nº 2 above.	Wolfe Nº 1: 6.2 gm. Nº 2: 6.7 gm. Nº 3: 8.2 gm.
5. *Plunger weight*	Plunger removed from tonometer and weighed on triple beam balance within an accuracy of 0.01 gm.	Wolfe Nº 1: 1.90 gm. Nº 2: 1.87 gm. Nº 3: 1.89 gm.

6. *Plunger load*

By "plunger load" is meant the spring tension acting against the plunger at a given indicator position. Naturally, the plunger load increases as the plunger is pushed into the instrument stem.

A small wooden block with a minute through its center projecting upward was placed upon the tray of the gravity balance and weighed. This weight was recorded and subtracted from each gross weight yielding the net values tabulated below.

The tonometer was carefully calibrated so as to read 70 mm. Hg. when placed upon its own test block.

The complete tonometer was supported by a laboratory jack by means of a clamp attached to its handle. The tonometer was lowered carefully so that its plunger rested upon the head of the nail.

The height of the laboratory jack was altered as were the positions of the balance weights until the balance indicator rested at zero at the same time that the tonometer needle rested at the indicated value.

These measurements were very difficult to make because of instrumental friction and in many cases a method of limits had to be used to determine the point of balance. Readings were made in multiple and averaged.

Indicator Value (mm. Hg.)	*Plunger Load Tonometer Nº 1 (gram.)*	*Plunger Load Tonometer Nº 2 (gram.)*	*Plunger Load Tonometer Nº 3 (gram.)*	*Plunger Load "Standard Instrument" (gram.)*
5	12.8	12.0	12.9	
15	15.6	14.7	16.0	
30	17.9	17.0	19.4	
60	19.8	19.0	22.1	
70	21.8	19.4	22.7	12.5

7. *Diameter of Footplate — Diameter of Plunger*

Measurements were made within an accuracy of 0.1 mm. by means of a vernier caliper. Data for the "standard" instrument was obtained by converting the manufacturer's specifications from inch measure to metric.

	Foofplate Diameter (millimeters)	*Plunger Diameter (millimeters)*
Wolfe Nº 1:	9.8	3.2
Wolfe Nº 2:	9.8	3.2
Wolfe Nº 3:	9.9	3.1
Standard:	10.109 to 10.160	3.175 ∓ 0.0254

8. *Radius of curvature of Foofplate — Radius of curvature of Plunger end*

Measurements were made to an accuracy of one half millimeter by utilizing a series of templates graduated in half millimeter steps.

	Radius - Footplate	*Radius - Plunger*
Wolfe Nº 1:	15	15
Wolfe Nº 2:	15	15
Wolfe Nº 3:	15	15
Standard:	15	15

COMPARISON OF THE THREE WOLFE INSTRUMENTS BY MEANS OF A TAMBOUR:

A tambour has at times been used for the purpose of comparing readings obtained under identical physical conditions by several different tonometric devices ([4c]). Identity of readings on the tambour tends to suggest instrumental similarity. Identity of readings on the tambour tends to suggest instrumental similarity. It does not, however, insure that identity of readings would be obtained if the tonometers were compared upon living human eyes with fixed tension. But, as human eyes with fixed tension are not readily available and as the use of the tambour yields results more satisfactory than those which would be obtained using human eyes with normal outflow characteristics, a tambour study was made. The bulb of sphygmomanometer was connected to a chamber covered by a thin plastics membrane, and to a pressure gauge reading in pounds per square inch. The reading of the pressure gauge did not hold any absolute relationship to the tonometer scale reading but merely indicated a pressure level at which the tonometric devices were being compared. The system was filled with air and testing was done at ascending pressure levels.

The tonometer under test was raised and lowered upon the tambour by means of a laboratory jack which eliminated the difficulty associated with repeated placement of a hand-held instrument upon a fixed area of the tambour.

TABLE III

Tonometer Readings Obtained at Various Tambour Inflation Levels with Each of Three Wolfe "C" Tonometers:

Tambour Inflation	*Tonometer Nº 1*	*Tonometer Nº 2*	*Tonometer Nº 3*
A	11.7 mm. Hg.	11.7 mm. Hg.	10.2 mm. Hg.
B	21.8 mm. Hg.	19.3 mm. Hg.	19.7 mm. Hg.
C	31.8 mm. Hg.	31.2 mm. Hg.	31.5 mm. Hg.
D	37.9 mm. Hg.	37.8 mm. Hg.	38.6 mm. Hg.
E	44.7 mm. Hg.	46.3 mm. Hg.	47.3 mm. Hg.

Table III shows the reading obtained at various pressure levels with each of the three Model "C" instruments. Measurements were made at each of five levels of tambour inflation labeled A, B, C, D, and E. Each reading was made in triplicate and averaged. Only the mean reading at each pressure level for each instrument is indicated in the table.

This table would seem to demonstrate that the three Wolfe instruments under test yield readings which are in reasonable agreement when applied in succession to a tambour maintained at a fixed level of pressure.

MANOMETRIC INVESTIGATION OF THE WOLFE CALIBRATION CURVE:

Closed stopcock calibration studies ([4d]) of a tonometric device are not entirely satisfactory because of the excessive scatter obtained when the tonometric readings are plotted against the manometric readings. The scatter is related to variations in the degree of ocular rigidity of the eyes under test. It is unfortunate that closed stopcock data are not well adapted to simple surve fitting because the closed stopcock situation more closely paralels the clinical condition than does the open stopcock situation.

Open stopcock data, ([4e]) on the other hand, are extremely useful in that scatter is reduced by the exclusion of rigidity effects. Open and closed stopcock curves have been assumed to be identical in contour but a vertical translation of the open stopcock curve upon its axes must be accomplished before it become representative of the clinical situation*.

A burette employed as a water reservoir was attached by means of pressure tubing to a manometer and to a twenty gauge needle inserted into the anterior chamber of a pig eye at the limbus. The system was filled with physiological saline and air was excluded. By the operation of a sphygomanometer bulb and burette valve the manometric pressure could be brought to any desired level. A Wolfe tonometer was clamped to a lab jack an lowered onto the bulbar conjunctiva of the pig eye so that the edge of the tonometer foot fell one half to one millimeter from the limbus. No eye was used in which the scleral radius exceeded fourteen millimeters as measured by means of a template. An area of sclera was utilized that was judged by inspection to be quite regular. Insertions of the extra-ocular muscles were avoided.

Figure 8 is a scatterplot in which the tonometer reading in millimeters of mercury (Wolfe) is plotted against the manometric determination of the actual internal pressure of the eye under open stopcock conditions. If the calibration curve of the eye Wolfe instrument were entirely accurate, a linear relationship should have been found between the tonometric pressure in millimeters of mercury and the manometric pressure in centimeters of water. * *

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* Identity of contour between the open and closed stopcock curves was assumed by Schiötz in his calibration studies. Such as assumption leads only to a very slight inaccuracy in the interpretation of clinical data. In more recent calibration studies, Friedenwald modified his curve by the utilization of a factor which takes into consideration the "normal" coefficient of ocular rigidity and the volume of fluid displaced by the tonometer plunger. The latter value is, of course, a function of the indicator position.

** In plotting open stopcock manometric values directly against the corresponding Wolfe scale values, the assupmtion was made that the open and closed stopcock curves deviated from each other by a constant value throughout their entire extent. This is an assumption which had been made by Schiötz in his calibration studies but is not entirely true. It is sufficiently precise for our present purpose, however.

SUMMARY AND CONCLUSION:

Scleral tonometry using the Wolfe instrument has recently aroused considerable interest. It has been shown that the Wolfe Scleral Tonometer constitutes a variant of the Bailliart corneal scleral instrument. The scleral escale of the Wolfe was found to be identical to the corneal scale of the Bailliart and to be quite irregular. The irregularity of the dial scale cannot be explained on the basis of the mechanical characteristics of the gear mechanism as this was established as being essentially linear over the major portion of its range. Further, it was demonstrated that the dial scale was not taken from the Schiötz calibration curve.

The effects of ocular rigidity upon the clinical estimate of the intra-ocular pressure are the critical pressure minimized when of the Tonometer is lower than the intra-ocular pressure. The critical pressure of a Wolfe Model "C" Tonometer was calculated and found to be in excess of sixty nine millimeters of mercury.

Although the dial of the Wolfe instrument implies a range from five to one hundred thirty millimeters of mercury, seventy millimeters of mercury constitutes the upper functional limit of the instrument.

While the Wolfe Tonometer is constructed in such a manner as to be usable with the patient either erect or reclining, it has been establishe that the instrument exerts a greater force upon the eye when held vertical rather than horizontal.

Whereas the plunger load assumes a constant value in a gravity type instrument, is varies as a function of indicator position in a spring loaded device such as the Bailliart or the Wolfe Tonometer. Although means are provided in the Bailliart Tonometer for adjusting plunger load, no means for insuring load are available in the case of the Wolfe instrument.

The physical characteristics of three available Wolfe instruments were measured and found not to be identical.

When the readings of three Wolfe instruments were compared on a tambour maintained at various pressure levels, reasonable consistancy was noted. Although this is suggestive of instrumental similarity, it does not insure that consistancy of readings would have been obtained had they been taken using human eyes with fixed tension.

An open stopcock manometric calibration study was undertaken using the Wolfe Tonometer to make pressure measurements on pig eyes maintained at known levels of pressure. When the tonometric findings were prottel against manometrics findings, the relation ship appeared not to be linear.

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Bloomington, Indiana

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4b. Pages 33-43.

4c. Pages 6-7.

4d. Pages 112-151.

4e. Pages 100-112.