

Effect of Corneal Thickness on Intraocular Pressure Measurements with the Pneumotonometer, Goldmann Applanation Tonometer, and Tono-Pen

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PURPOSE. To compare intraocular pressure (IOP) measurements of the Ocular Blood Flow (OBF) pneumotonometer, Goldmann applanation tonometer, and Tono-Pen in eyes with normal corneas of various thicknesses.

METHODS. IOP was measured with an OBF pneumotonometer, Tono-Pen and Goldmann applanation tonometer in random order in 181 eyes with normal corneas. Central corneal thickness (CCT) was measured using an ultrasonic pachymeter after all IOP determinations had been made. Right and left eyes were analyzed separately for statistical purposes.

RESULTS. With all instruments, IOP varied with CCT, even though the variation in IOP was large. Readings with the OBF pneumotonometer showed a mean increase in IOP with increasing CCT of 0.28 mm Hg/10 μ m, an increase of 0.23 mm Hg/10 μ m with the Goldmann tonometer, and of 0.10 mm Hg/10 μ m with the Tono-Pen. The OBF pneumotonometer consistently recorded comparatively higher IOPs than the other two instruments.

CONCLUSIONS. The Tono-Pen is least affected by CCT when used to measure IOP in eyes with normal corneas. The OBF pneumotonometer appears to be more affected by variation in CCT than the Goldmann tonometer. This is contrary to expectations, based on the mechanism of measurement of IOP of the OBF pneumotonometer. (*Invest Ophthalmol Vis Sci.* 2002;43:1389-1392)

Although Goldmann tonometry is probably the most widely used method of measuring intraocular pressure (IOP), it has been shown that IOP measurement is affected by differing central corneal thicknesses (CCTs).¹⁻¹¹ This study was designed to compare the effect of different CCTs on the IOP measured by the Goldmann applanation tonometer (Haag-Streit, Switzerland), Tono-Pen (Mentor Ophthalmics Inc, Norwell, MA), and Ocular Blood Flow (OBF) pneumotonometer (OBF Laboratories, Malmesbury, UK).

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METHODS

IOP was measured in random order (to allow for changes in IOP produced by applanation of the cornea) by the Goldmann applanation tonometer, Tono-Pen XL, and OBF pneumotonometer in 181 normal corneas of 94 patients. The research adhered to the tenets of the Declaration of Helsinki. Measurements were taken by experienced ophthalmologists after informed consent was obtained from patients attending a general eye clinic over a 6-month period. A series of measurements with the three instruments and pachymetry on an individual eye were performed by a single ophthalmologist. The cornea was anesthetized with unpreserved lidocaine 4% combined with fluorescein 0.25% (Chauvin Pharmaceuticals, Ltd., Montpellier, France).

Goldmann applanation tonometry was performed in each eye three times and the mean result recorded. Corneal astigmatism was not measured. Tono-Pen tonometry was performed on the central cornea using an instrument calibrated according to the manufacturer's instructions. All measurements were made with a disposable latex cover over the tip, which was renewed after each patient. The results of the IOP reading were accepted if the confidence interval was greater than or equal to 95%. OBF pneumotonometry was performed with the updated slit lamp-mounted probe, in patients sitting upright. Each day before measurements were made, the air pressure generated by the instrument was checked with a manometer and was calibrated according to the manufacturer's instructions. Patients were instructed to look at the red fixation target within the probe. The probe tip was applied to the central cornea and, when correctly aligned, a whistling noise sounded. The probe was kept applied to the cornea until five pulses of equal amplitude were recorded. The mean IOP was calculated by the instrument and displayed on an LCD. After all IOP measurements had been made, CCT was measured in each eye with an ultrasonic pachymeter (model SP-2000; Tomey Corp, Cambridge, MA).

For each method of measurement, a regression equation was calculated after plotting IOP against CCT. From the graphs, the apparent increase in IOP per 10- μ m increase in CCT was calculated for each instrument. The mean IOP measurements by each of the Tono-Pen and OBF instruments were compared with the measurement by the Goldmann applanation tonometer, by Student's *t*-test. All statistical analyses were performed by computer on right eyes only, to reduce bias (SPSS for Windows, ver. 10.0; SPSS Inc, Chicago, IL).

RESULTS

The mean (\pm SD) CCT of the group was 551.53 \pm 0.49 μ m. Figure 1 shows IOP versus CCT for each tonometer. Although it may appear that there is a large variation around the mean for all instruments, this is in fact because there was a wide range of IOPs in the subject group. Linear regression analysis shows that the Tono-Pen was least affected by differences in CCT, followed by the Goldmann tonometer. The OBF pneumotonometer was most affected by these differences (Table 1).

Student's *t*-test analysis of the mean IOPs showed that the differences in readings between the Tono-Pen and the Gold-

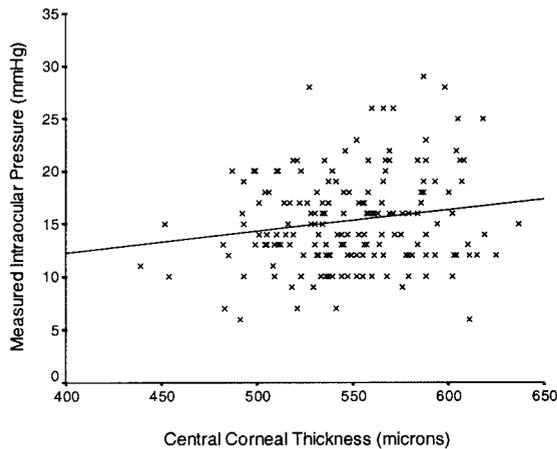
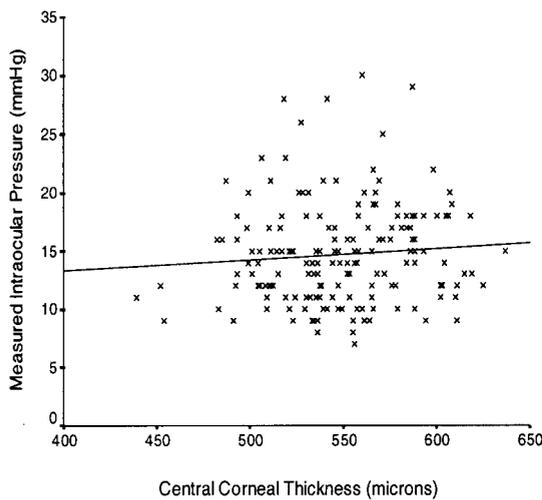
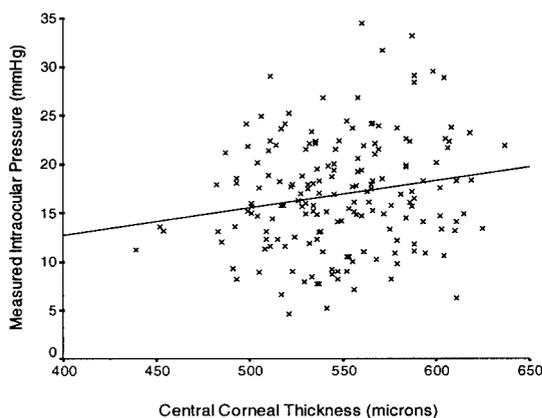
a GOLDMANN TONOMETER**b TONO-PEN****c OBF PNEUMOTONOMETER**

FIGURE 1. Effect of CCT on IOP measurement with the (a) Goldmann tonometer, (b) Tono-Pen, and (c) OBF pneumotonometer

mann tonometer were not statistically significant ($P = 0.34$). However, there were significant differences between the readings of the Goldmann tonometer and the OBF pneumotonom-

eter ($P < 0.001$) and those of the Tono-Pen and the OBF pneumotonometer ($P < 0.001$), with the OBF consistently recording comparatively higher IOPs. The Tono-Pen appeared to be least affected by the various thicknesses of different corneas, whereas the OBF pneumotonometer appeared to be most affected.

DISCUSSION

Despite numerous studies and publications, ophthalmologists frequently do not make an association between IOP and corneal thickness. A wide choice of instruments is now available to measure IOP. Goldmann applanation tonometry is widely accepted as the international gold standard for measurement of IOP and is the most commonly used method.¹² However, its use provides only an estimate. Its accuracy depends on many factors.¹³ Goldmann predicted that applanation tonometry would be affected by differences in CCT¹⁴ but believed that there would only rarely be significant variations in CCT from the mean of 500 μm . Several studies have examined the variation of CCT in eyes of different patient groups, especially those with ocular hypertension (OHT), normal-tension glaucoma (NTG), and primary open-angle glaucoma (POAG).¹⁻¹¹ CCT has been shown to be increased in patients with OHT.³⁻⁸ Eyes in patients with a diagnosis of NTG have been found to have a lower mean CCT than that of patients with POAG.^{6,7,9-11} Eyes with thicker corneas than normal (as in patients with OHT), may have IOP overestimated. Similarly, eyes with thinner than average corneas (such as those in patients with NTG) may have IOP underestimated.

Obviously, this has important implications in diagnosis and management. It is thus especially important that we know how much different tonometers are affected by different corneal thicknesses, so that we can make appropriate allowances. Furthermore, with the potential risk of transmission of prion proteins, there is a move toward using disposable tonometer heads or protective coverings. In many clinics in Europe, ophthalmologists are switching to the Tono-Pen because of the protection offered by the disposable sheaths. Similarly, the OBF comes with a disposable head and offers the same advantage. If pressures recorded by different instruments in the same patient are to be considered, it is important that we compare these instruments and ascertain the extent to which each may be affected by variables such as corneal thickness.

Shah et al. compared manometric intracameral pressure against Tono-Pen recordings and demonstrated that the Tono-Pen is only slightly affected by corneal thickness (Shah, American Academy of Ophthalmology, New Orleans 1998). Feltgen et al.¹⁵ compared the Perkins (Clement Clarke International, UK) and Tono-Pen against manometric measurements and found that the two instruments correlated well and their IOP measurements did not increase significantly with increasing CCT. This corresponds with the findings of our study, in which the slope of the readings (IOP versus CCT) was flattest with the Tono-Pen. Although it was comparatively steeper with the Goldmann tonometer, the difference was not statistically sig-

TABLE 1. Mean IOP \pm SD and Increase in IOP for Every 10- μm Increase in CCT for Each Instrument Tested

Instrument	Mean IOP \pm SD	Increase in IOP ($\mu\text{m Hg}$)
Goldmann	14.65 \pm 5.03	0.10
Tono-Pen	14.39 \pm 4.87	0.23
OBF Pneumotonometer	16.43 \pm 6.36	0.28

nificant. The steeper slopes for the OBF pneumotonometer indicate that it is affected significantly by CCT. It therefore implies that the two applanation instruments are affected less than the contact pneumotonometer.

The Tono-Pen is a small, computerized, handheld instrument that operates on the MacKay Marg principle. It is thought to be relatively unaffected by corneal surface abnormalities,¹⁶ unless these are gross (e.g., band keratopathy or glued corneas).¹⁷ Previous studies have shown the Tono-Pen to compare favorably with Goldmann tonometry in normal corneas¹⁸⁻²⁰ and within normal IOP ranges. Recently, a new instrument has become available to measure IOP by contact pneumotometry, the OBF pneumotonometer. This is a modified version of that first described by Langham²¹ and allows measurement of IOP, pulse rate, pulse amplitude, and pulsatile ocular blood flow. The principle of action and the calculation of IOP are complex and are described in detail elsewhere.²² Essentially, the cornea is applanated by a force that is proportional to the initial IOP but is not measured by the pneumotonometer. The resistance to the airflow through the center of the tonometer is then measured.

Theoretically, it has been claimed that the calculation of IOP by pneumotonometers is not affected by CCT, because flexural rigidity of the cornea can be ignored.²³ Measurements with the OBF pneumotonometer have been shown to be reproducible,²⁴ and it has been shown to correspond well with the Goldmann tonometer in patients without corneal disease,²⁵ not considering CCT. Although in theory the OBF pneumotonometer should not be affected by CCT, the results of this study suggest otherwise. This probably reflects the mechanism by which it measures IOP. During measurement, the tip of the pneumotonometer is applanated to the cornea. Gas at constant pressure flows down a central hollow tube, pushing against a terminal membrane, deforming the cornea. The gas then escapes into the atmosphere. The resistance offered to the gas is measured as the IOP. This resistance is determined by the IOP and the corneal elastic forces (including CCT).²¹ Unlike the Goldmann and Tono-Pen instruments, with which the balance of applanating forces on the one hand and IOP and corneal rigidity on the other are the end points of measurement, with the pneumotonometer, the pressure of the air flow has to exceed this equilibrium, to escape. Hence, it is likely that corneal thickness affects the measurements and also that the readings will be higher than recorded by the other instruments. This was indeed what we observed in this study.

In our study, all three instruments were affected by CCT to various degrees. The Tono-Pen appeared to be least affected by different corneal thicknesses and the OBF pneumotonometer appeared to be most affected. There was no statistically significant difference between the readings of the Tono-Pen and the Goldmann tonometers. Another study testing the Tono-Pen with various CCTs shows that IOP increases by 0.29 mm Hg in males and 0.12 mm Hg in females, per 10- μ m increase in CCT.²⁶

The Goldmann tonometer was the easiest instrument to calibrate, whereas there was no external check possible on the accuracy of the Tono-Pen calibration system because of the instrument's design. The OBF pneumotonometer was the most difficult, uncomfortable, and time-consuming instrument to use, whereas the Goldmann tonometer and Tono-Pen subjectively appeared similar in ease of use for the operator and the comfort of the patient.

We acknowledge that we did not measure astigmatism before measuring IOP and that this may have some impact on the results obtained from the Goldmann tonometer. Another limitation could be that the instruments were used in random order rather than in the same order and with different opera-

tors. However, the large number of patients sampled in the study is likely to mitigate the potential effects of these variables.

These findings serve to highlight that IOP measurement alone may be misleading. IOP may need adjustment in patients with CCTs that differ from the population mean. In addition it is important to note that each instrument tested was affected by CCT to differing degrees. These results have important implications in the choice of tonometer for use in patients with different corneal thicknesses in midpressure ranges. Because the Tono-Pen was relatively easy to use and least affected by thickness of various corneas, it seems to be the instrument to use in these patients.

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