Error Measurement for a Portable Tonometer

Peter Marchetto[1, 2], Tara Alvarez[3], Richard Greene[3], Gordon Thomas[1, 3]
Department of Physics, New Jersey Institute of Technology [1] Newark, NJ; Academy for the Advancement of Science and Technology, Bergen County Academies [2] Hackensack, NJ; Department of Biomedical Engineering, New Jersey Institute of Technology [3] Newark, NJ

Abstract- **Most patients with glaucoma exhibit elevated intra-ocular pressure (IOP). A cost effective device that allows the patient to measure IOP at regular intervals may reduce vision loss. This research tested the Bausch & Lomb Proview self tonometer against a calibrated force meter. It further compared the Proview tonometer with results from the clinical gold standard, the Goldmann tonometer. Results show that the Proview tonometer has inaccuracies in calibration and uncertainties in clinical applications. If the Proview's calibration is corrected (using our results, e.g.), and the inaccuracies can be reduced, a device like the Proview has the potential to be clinically useful.**

I. INTRODUCTION

To date, patients who were at risk for, or have, glaucoma, have typically had their intra-ocular pressure (IOP) measured by a trained clinician. This option, although relatively reliable, has limitations in terms of the cost and frequency of measurements. In some glaucoma patients, IOP varies significantly throughout the day, and the extent of this diurnal variation correlates with the rate of vision loss [1].

Consequently, there is a need for a device that allows the patient to measure his or her own IOP easily. In Figure 1, a schematic drawing is shown of the Proview [2] made by Bausch & Lomb, Incorporated. Devices of this type are designed to satisfy this need. The instructions for this device instruct the user to press the device to the eyelid until a small dark circle in the field of vision opposite to the site of application can be seen. This visual sensation, is called a 'phosphene' spot [3].

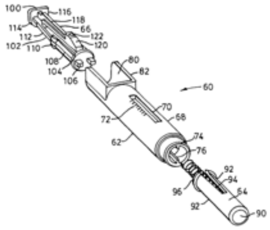

Fig 1. Schematic Drawing of Proview

II. METHODOLOGY

We have carried out vertically opposed force tests, wherein the tonometer itself is lowered via a dovetail slide onto a calibrated, digital force meter. The meter records the force in mass units (grams) at the same time that we record the Proview scale readings. Data is taken at the 10, 20, 30, and 40 mmHg (Torr) markings on the Proview. These data are then converted from grams to mm Hg by using a formula inclusive of the diameter of the tonometer head, (part #90 in Figure 1) in Formula 1.

The methodology that was used is indicated in Figure 2. The tonometer was placed into a clamp, which holds the tonometer against the scale or force gauge for the measurement of pressure. The force gauge used in Figure 2 is not the same one that was used in the actual experiments, but performs the same function. The Proview shown is one of the three devices that we tested. The tonometer is then lowered onto the scale using the micrometer attached to the side of the dovetail slide. As the indicator reaches each of the 10, 20, 30, and 40 mm Hg marks, a measurement of the force, in grams, is taken.

$$\left(x(g)\right)\times\left(\frac{0.001(kg)}{\pi(0.003175)^2(m^2)}\right)\times\left(\frac{9.8(m)}{(s^2)}\right)\times\left(\frac{1(atm)}{1.013\times10^5(Pa)}\right)\times\left(\frac{760(mmHg)}{1(atm)}\right)$$
$$= 2.34\,(m\text{m Hg/g}) \qquad (1)$$

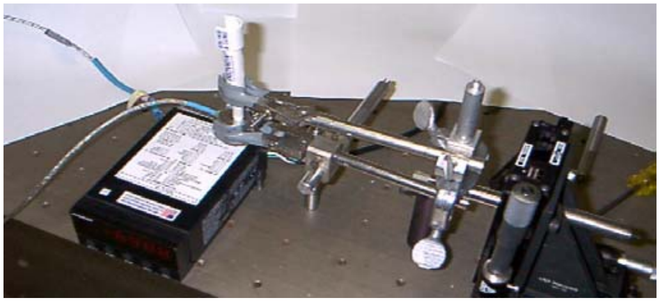

Fig 2. Experimental Set-up

III. RESULTS

The graph in Figure 3 summarizes the readings from the digital force meter, which are accurate to three significant figures, P_a, as a function of the Proview scale reading, P_P, throughout the scale range of the Proview. The line through the data is a cubic fit to the function

$$P_a = 8.5 + 1.03P_P - 0.001\,P_P^{\,2}\,. \qquad (2)$$

This polynomial is not necessarily the optimized fit that could be obtained with additional measurements, since we expect a simple, linear behavior for small spring displacements, but it is a good description of our present data. If the two scales were in agreement, we would measure

$$P_a = 1\,P_P. \qquad (3)$$

Figure 4 is a summary of data taken using a group of clinical volunteers under the supervision of physicians at the University of Medicine and Dentistry of New Jersey [4]. Both the eye pressure as taken by the patients (all normal) using the Proview and that as measured immediately afterward by a physician using a Goldmann tonometer (the clinical gold standard) were recorded. Each data point is one patient's results displaying the mean and standard deviation of 25 readings from the Proview self tonometer (5 readings from 5 different devices) and 2 readings from the Goldmann tonometer. The primary result is that the data show a large measurement uncertainty. If the readings had no uncertainty and the calibrations were in agreement they would fall on the solid line. Because of the scatter, it is hard to assess the relative calibrations, but we have checked the accuracy of the Goldmann using its built-in calibration accessory, and found it to have negligible error.

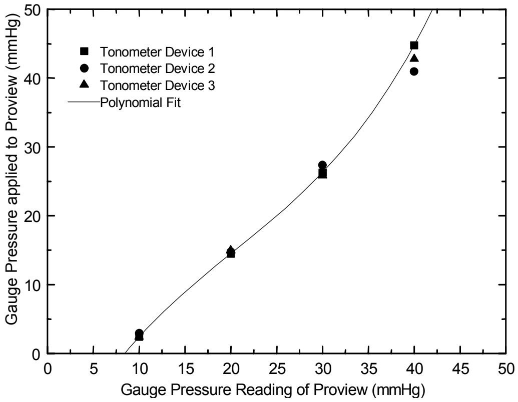

Fig 3. Applied Pressure vs. Recorded Pressure

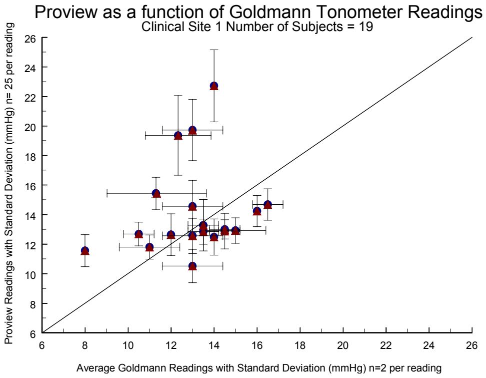

Fig 4. Clinical Data comparing Goldmann to Proview

IV. DISCUSSION

The limitations of the Proview are found in two types of errors. First, is the Proview scale calibration, shown in Figure 3, which we attribute simply to a mis-labeling of the pressure readings on the Proview. This error can be corrected by simply using Figure 3 or Equation (2) to convert to true pressure. The Proview's scale contains errors in its zero (too large by 6.7 (mmHg), in the slope of the linear region (too large by a factor of about 2.5), and in the failure to account for the non-linearity (a general feature of springs, that can be accounted for by higher order terms beyond the linear behavior described by the well-known Hooke's law). The combination of these errors makes the Proview's readings less problematic in the range of normal eye pressures of 10-20 (mmHg) and accounts for why the calibration accuracies are hard to detect in the comparison of tonometer readings on normal patients, as illustrated in Figure 4.

The second type of limitation of the Proview is the uncertainty and lack of reproducibility. These factors are relatively small in the carefully controlled laboratory measurements shown in Figure 3, where the uncertainty is the size of the symbols plotted. Because of this accuracy, we conclude that the variations in the readings in Figure 3 above 40 (mmHg) are due to differences in the three devices, probably in the springs. However, these uncertainties are large as indicated by the scatter of the data in Figure 4. Both the variation in the Proview readings and in the Goldmann readings contribute as indicated by the bars on the data points, indicating the variation in repeated measurements.

The uncertainty in any tonometer is partly related to the way in which the measurement is made. In the Proview, for example, the frictional force in the mechanical interfaces of the plastic may be too great. This force arises at the interface between the plastic case and the spring. The static friction coefficient, μ_s varies [5] as the load L, in some ranges of force as $\frac{1}{L} \propto \mu_s$.

Another uncertainty factor is the angle at which the tonometer is held during measurement, which will be ±10° from the horizontal, when normally measuring the eye. This factor affects our calibration slightly because the vertical orientation in our measurement adds a force from the mass of part of the Proview according to F=mg.

Also, the accuracy of a self-use tonometer, such as the Proview, is limited by the method used to move the tonometer to the correct measuring position.

Beyond the calibration errors and the uncertainty, other factors affect of the measurement on the eye. Further investigations should be carried out to determine if the repeated external pressure required for a measurement like that of the Proview will cause further damage to individuals with glaucoma. Furthermore, if the glaucoma is advanced and the patient is beginning to lose part of his or her visual field, the phosphene spot may not be observable.

Future direction of this work includes an attempt to construct an alternative, cost-effective, portable tonometer that is more accurate and precise than the Proview. After the completion of the design of a satisfactory tonometer is accomplished studies can begin to investigate the correlation between IOP and various parameters, such as environmental pressure, stress, diet, daily activities, etc.

ACKNOWLEDGMENTS

This work was funded in part by a grant from the New Jersey Institute of Technology, and made possible by a special laboratory research program of the Bergen County Academies. We thank Dr. Robert Fechtner of the University of Medicine and Dentistry of New Jersey for the loan of his tonometers and access to his clinical data.

REFERENCES

[1] S. Asrani, R. Zeimer, J. Wilensky et al. "Large diurnal fluctuations in intraocular pressure are an independent risk factor in patients with glaucoma" *J. Glaucoma.* Vol 2pp. 134-142, 2000.
[2] B. B. Fresco, J. G. Dayman, US Patent # 6,251,071, US Patent and Trademark Office, June 2001.
[3] F. H. Adler, "Entopic and Allied Phenomena" in *Physiology of the Eye: Clinical Application*, St. Louis: The C. V. Mosby Co., 1950, p. 664
[4] S. Gollance and R. Fechtner, private communication, to be published.
[5] I. F. Brown, Abrasion and Friction in Parallel-lay Rope Terminations, Ph.D. Thesis, University of Cambridge, UK, March 1997. sec. 3.2.2.