

Pressure Phosphene Self-Tonometry: A Comparison with Goldmann Tonometry in Glaucoma Patients

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PURPOSE. To evaluate whether the pressure phosphene tonometer (PPT) is suitable for self-tonometry in patients with glaucoma or ocular hypertension.

METHODS. This was a prospective comparative study of 102 eyes of 102 patients with chronic glaucoma or ocular hypertension. Intraocular pressure (IOP) measurements by the Goldmann tonometer (GT) were compared with self-measured readings with the PPT. Patients evaluated the ease of home use of the PPT. The last 15 patients were asked to stop their glaucoma medications, and the ability of the PPT to detect an elevated IOP during self-tonometry was studied.

RESULTS. The mean \pm SD difference between PPT and GT readings was -0.24 ± 1.57 mm Hg. Comparing the PPT with the GT, 86% of the readings were within ± 2.0 mm Hg, and 91% were within ± 3.0 mm Hg. Spearman's correlation coefficient was 0.91. A Bland-Altman plot showed that the 95% limits of agreement between the two methods lay between 2.90 and -3.38 mm Hg. Within-subject coefficients of variation for the GT and the PPT were 4.4% and 7.3%, respectively. In detecting an elevated IOP of more than 21 mm Hg, the sensitivity and the specificity of the PPT were 92.3% and 98.6% respectively. The mean satisfaction score for home use of the PPT was 87.4 ± 16.3 (maximum 100).

CONCLUSIONS. With proper training and technique, self-tonometry with the PPT appears to be accurate up to at least 25 mm Hg and is reproducible. The PPT was sensitive and specific in detecting an elevated IOP of more than 21 mm Hg. As patients were expected to seek ophthalmic care before the self-measured IOP reaches 25 mm Hg, the PPT may have a value for self-monitoring. Patients rated the PPT as satisfactory for home use. Because the PPT is portable and relatively inexpensive and requires no topical anesthesia or direct contact with the eyeball, it may have potential as an instrument for home self-tonometry. (*Invest Ophthalmol Vis Sci.* 2004;45:3131-3136) DOI:10.1167/iovs.04-0115

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Supported in part by Bausch & Lomb Co., Ltd, Tampa, Florida.

Submitted for publication February 5, 2004; revised April 1, 2004; accepted April 14, 2004.

Disclosure: **D.S.C. Lam**, Bausch & Lomb (F); **D.Y.L. Leung**, None; **T.Y.H. Chiu**, None; **D.S.P. Fan**, None; **E.Y.Y. Cheung**, None; **T.-Y. Wong**, None; **J.S.M. Lai**, None; **C.C.Y. Tham**, None

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Self-monitoring of disease has long been of proven value. For example, home blood glucose monitoring is regarded as a cost-effective and simple tool for improving the quality of life and prognosis of diabetic patients.¹ Glaucoma is a major cause of blindness. Self-monitoring of intraocular pressure (IOP) has been proposed to be useful for glaucoma management.² Home IOP monitoring can help early detection of unsatisfactory IOP control and its daily fluctuation. Poorly controlled IOP and large diurnal fluctuations are significant risk factors for disease progression.³

No ideal home IOP monitoring device is currently available. Such a device should be accurate and reliable, simple to use, safe, acceptable to the patient, and inexpensive. Several instruments have been proposed,^{2,4-7} but they are too expensive, too complicated, or not safe enough to be operated by patients.

The pressure phosphene tonometer (PPT) is a new device using the entoptic phenomenon of pressure phosphene to evaluate IOP.⁸ The PPT is applied through the eyelid, and no direct eyeball contact or topical anesthesia is required. Previous data have shown that the PPT, when used by professionals on patients, can produce accurate IOP measurements comparable to the Goldmann tonometer (GT), the gold standard of IOP measurement.⁸ There are, however, no data on using PP self-tonometry in patients with glaucoma. The intent of this study was to determine the accuracy and reproducibility of PP self-tonometry compared with the GT in patients with glaucoma or ocular hypertension. We then studied whether the PPT could detect an elevated IOP during self-tonometry.

METHODS

We conducted a prospective comparative study of patients with various types of chronic glaucoma or ocular hypertension. The study followed the guidelines of the Declaration of Helsinki and was approved by the ethics committee of The Chinese University of Hong Kong. Written informed consent was obtained from each participant. Subjects were recruited at the Hong Kong Eye Hospital between January and February 2002. Glaucoma was diagnosed on the basis of glaucomatous optic disc changes,⁹ with or without glaucomatous visual field loss, as defined by Anderson's criteria.¹⁰ For those with normal visual fields, glaucoma was considered present if there was documented progression of optic disc cupping. Elevated IOP was not required for diagnosing glaucoma. Ocular hypertension was defined as IOP of 22 mm Hg or more, with a normal optic nerve head, normal gonioscopy, and visual field. IOPs were determined by Goldmann applanation tonometry (model 900.4.4; Haag-Streit, Gartenstadtstrasse, Switzerland). Visual field tests were performed with a visual field analyzer (Humphrey SITA 24-2 Standard; Carl Zeiss Meditec, Dublin, CA). Central corneal thickness was measured by ultrasound pachymetry (DGH-1000; DGH Technology Inc., Exton, PA). Exclusion criteria were previous ocular surgery and acute ocular inflammation.

In the first study visit, patients underwent training for the use of the PPT (Fig. 1; Proview Eye Pressure Monitor; Bausch & Lomb Inc., Tampa, FL), as follows: The PPT was first reset to the lowest pressure reading of 8 mm Hg on the graticule. The patient was then instructed to look down and out and to place the PPT on the superonasal portion

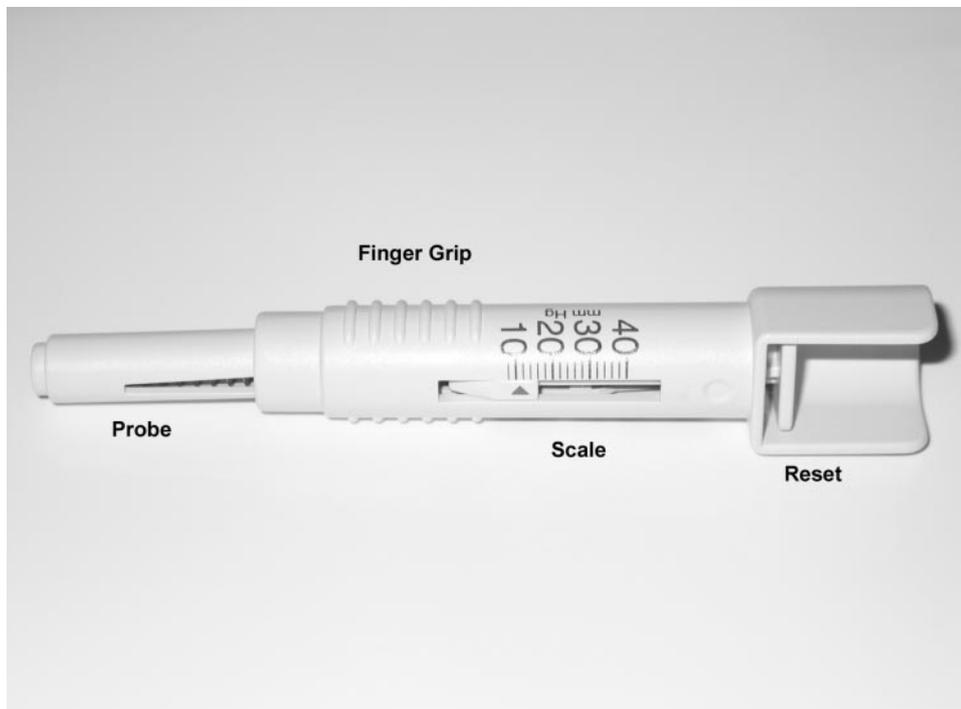


FIGURE 1. The PPT with its various components.

of the eyeball through the upper eyelid. The patient was taught to make the applicator surface lie tangential to the eyeball; in other words, the direction of application was perpendicular to that part of the eyelid and the eyeball. Afterward, the application pressure was increased gradually. The end point was taken as the moment when the patient clearly perceived a well-formed phosphenes with a central dark spot, with or without a glowing outer rim (Fig. 2). The patient was instructed to remove the tonometer from the eyelid as soon as the end point was reached. The IOP could then be read from the graticule on the dial. The graticule has a fiduciary indicator that does not move from the highest reading until it is reset. All training was given by a single trainer (EYYC) for better standardization of technique. The training of each patient lasted approximately 1 hour. The characteristics of the phosphenes perceived were recorded. Afterward, the patient was requested to practice with the PPT for approximately 1 hour to ensure he or she had acquired the proper technique with adequate skill and safety.

One eye of each patient was randomly selected. We took three IOP measurements by GT, and three IOP measurements were performed

with the PPT by the patients themselves. The two instruments were used in random order, so that half of the subjects were tested with GT first, and the remaining half was tested with the PPT first. This was intended to compensate for the massaging effect of Goldmann tonometry, which lowers IOP.¹¹ The median of the three readings was taken. We chose the median instead of the mean to provide a more stable estimate. All measurements were taken within a few minutes of each other to reduce diurnal variation. Moreover, all measurements were taken in the afternoon between 1 and 5 PM. All GT measurements were performed by two of the investigators (DYLL, TYHC) in a standardized manner, as published.¹¹ The two tonometric techniques were applied independently with the results of the other technique masked to the investigators and patients.

The patient was then asked to measure his or her IOP in each eye at home by the PPT three times a day (morning, afternoon, and evening) for 1 week and to record the readings in a logbook. This served as a further self-practice in using the PPT, as well as a test for its ease of use at home.

A



B



FIGURE 2. A pressure phosphenes as viewed by the left eye of a study subject. (A) Normal vision; (B) with pressure phosphenes.

TABLE 1. Characteristics of the 102 Patients (102 Eyes)

Characteristic	
Age (y, mean \pm SD)	54.3 \pm 12.6
Diagnosis: (n, % of all 102 patients)	
Glaucoma	77 (75.5)
Ocular Hypertension	25 (24.5)
Mean (range) best corrected Snellen visual acuity	
Right eye	0.73 (0.1-1.0)
Left eye	0.73 (0.2-1.0)
Mean central corneal thickness (μm \pm SD)	
Right eye	560.3 (38.7)
Left eye	560.1 (38.7)
Visual field status (n, % of all 102 patients)	
No field loss	50 (49.0)
Field loss over both eyes	29 (28.4)
Field loss only in one eye	23 (22.5)

In the second study visit at week 1, we similarly measured IOP three times by GT, and three PPT measurements were taken by patients. The two tonometries were again performed in random order. All measurements were again taken in the afternoon between 1 and 5 PM. The median of three readings was calculated. The patient was then requested to rate the ease of use of the PPT in home self-tonometry and the ease to perceive the phosphene. A simple rating system was adopted to determine the ease of use of the PPT at home and of perceiving the phosphene. The rating scale was a continuous scoring system from 0 to 100, with the following definitions, according to the patients' experiences: 0, very great difficulty; 25, great difficulty; 50, some difficulty; 75, easy; and 100, very easy to use the PPT at home and perceive the phosphene.

The last 15 patients were further asked to stop their glaucoma medications for 10 days, after taking the baseline IOP. During the 10 days, they were requested to perform home self-tonometry with the PPT at 2 PM every day. They were asked to come back immediately for advice if their home tonometry readings were 30 mm Hg or above. A further visit on day 10 was scheduled for repeating GT and PPT measurements at 2 PM. The patients resumed all glaucoma medications on exit.

Statistical Analysis

All data were analyzed on computer (Statistical Package for the Social Sciences for Windows, ver. 11.0; SPSS Science, Inc., Chicago, IL). A Bland-Altman plot¹² of the difference between PPT and GT readings against the average of the two was drawn to assess the agreement between the two methods and the presence of systemic bias. The medians of the PPT and GT readings at the initial and week-1 visit were compared using the Wilcoxon signed rank test or the Kruskal-Wallis one-way analysis of variance for subgroups. The mean differences and Spearman's correlation were computed for median PPT versus GT readings. The within-subject reproducibility for PPT and GT measurements was examined by calculating the within-subject coefficient of variation (CV) using the root mean square method as previously reported.¹³ $P < 0.05$ was defined as statistically significant. Pair-wise data exclusion was used for handling any missing data.

RESULTS

We screened 306 consecutive patients with glaucoma. One hundred two patients (102 eyes) participated in the study. The rest of them were either not interested in self-tonometry (20 eyes) or were excluded because of previous ocular surgery (184 eyes). Baseline characteristics of the patients are shown in Table 1. The mean age (\pm SD) of our subjects is 54.3 \pm 12.6 years, and the mean (range) of best-corrected Snellen visual acuity is 0.73 (0.1-1.0). The mean central corneal thickness of our subject was 560.3 \pm 38.7 μm . Three patients were unable

to perceive the pressure phosphene, leaving 99 eyes at initial visit. Two patients were lost to follow-up, leaving 97 eyes at week 1.

The median PPT readings and GT readings for each eye are shown in Figure 3. The mean (of the median IOP readings across subjects) in the initial and 1-week visit for the PPT and GT are shown in Table 2. The distribution of GT and PPT IOPs are shown in Figure 4. There was no statistically significant difference between the mean IOP readings taken by the GT and the PPT at both the initial visit (Wilcoxon signed rank test, $P = 0.456$) and the 1-week visit (Wilcoxon signed rank test, $P = 0.225$).

The mean difference between PPT and GT readings at the initial visit was 0.11 \pm 2.46 mm Hg. After 1 week of PPT use at home, the mean difference was -0.24 ± 1.57 mm Hg. The distribution of differences is shown in Figure 5. Using the week-1 visit data, 86% of the differences in IOP readings were within ± 2.0 mm Hg and 91% were within ± 3.0 mm Hg between the two methods. The Spearman correlation of the PPT and GT was 0.82 at the initial visit and 0.91 at the 1-week visit. The Bland-Altman plot for examining the extent of agreement between PPT and GT is shown in Figure 6. It showed that 2 SD, or 95% limits of agreement, of the differences in IOP measured between the two methods lay between 2.90 and -3.38 mm Hg.

The within-subject reproducibility of the two instruments was then examined. Using 194 measurements for the GT and 194 measurements for the PPT, the within-subject coefficient of variation for the GT was 4.4% and that for the PPT was 7.3%.

Fifteen patients were asked to stop their glaucoma medications. At the initial visit, the mean \pm SD. IOP readings were 17.9 \pm 3.1 mm Hg by the GT and 17.6 \pm 3.4 mm Hg by the PPT. After partial cessation of medications, at day 10 the mean \pm SD IOP was 23.7 \pm 4.5 mm Hg by the GT and 23.0 \pm 4.5 mm Hg by the PPT (Table 2). Wilcoxon signed rank test between readings at the initial and day-10 visits showed a statistically significant difference with $P = 0.001$. This is true for both GT and PPT measurements. There was no case in which IOP was elevated to more than 30 mm Hg. The correlation coefficients between GT and PPT were 0.93 (initial visit) and 0.98 (day 10 visit) in this group. Using the IOP measured

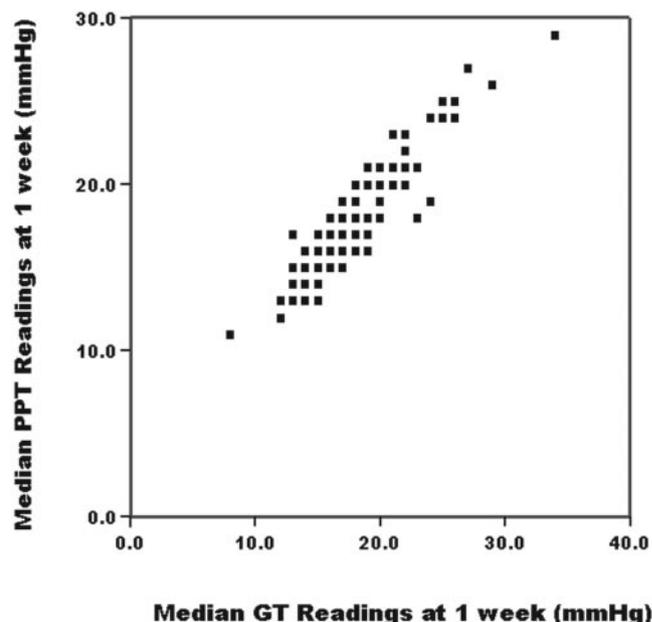


FIGURE 3. A scatterplot of PPT readings against GT readings for each eye. Data are from the week-1 visit.

TABLE 2. Summary of Measurements with Goldmann Versus Pressure Phosphene Tonometer

	Visit	Eyes (n) (GT/PPT)	Mean GT IOP (\pm SD)	Mean PPT IOP (\pm SD)	Mean Difference (\pm SD)	Correlation Coefficient (Spearman)	P*
All patients	Initial	102/99	19.1 (4.7)	19.2 (4.0)	0.11 (2.46)	0.82	0.456
	One week	99/97	18.6 (4.1)	18.4 (3.4)	-0.24 (1.57) [†]	0.91	0.225
15 Patients Who stopped medications	Initial	15/15	17.9 (3.2)	17.7 (3.3)	-0.14 (1.23)	0.93	0.671
	Day 10 [‡]	15/15	23.9 (4.5)	23.0 (4.3)	-0.93 (1.00)	0.98	0.523

* Wilcoxon signed rank test; between GT & PPT readings in a same visit.

[†] Eighty-six percent of the differences were within 2.0 mm Hg, and 91% of the differences were within 3.0 mm Hg between the two methods.

[‡] There was a statistically significant increase in IOP at day 10 versus IOP at the initial visit, for GT measurements ($P = 0.001$; Wilcoxon signed rank test), and PPT measurements ($P = 0.001$; Wilcoxon signed rank test).

by GT as the gold standard, we calculated the sensitivity and specificity of the PPT in diagnosing increased IOP (>21 mm Hg). Based on data at the week-1 visit, in 24 eyes results were true positive, in 2 eyes were false negative, in 70 eyes were true negative, and 1 eye are false positive. These gave a sensitivity of 92.3% and a specificity of 98.6%.

Three (2.9%) of the 102 subjects failed to perceive a pressure phosphene (group 1). Only one of the three subjects had visual field defects, with a mean defect of -6.73 dB ($P < 0.5$). For the remaining two subjects, their best-corrected Snellen visual acuities were fair at 0.6 and 0.2, respectively. Seventy-six subjects (74.5%) could see the black spot plus the glowing outer rim clearly (group 2). There were 23 (22.5%) subjects who could see only the black spot without the glowing outer rim (group 3). There was no statistically significant difference in age between groups 2 and 3. We compared the GT IOP readings of the three groups. The mean \pm SD IOP by the GT for groups 1 (3 eyes), 2 (76 eyes), and 3 (23 eyes) were 17.4 ± 3.8 , 18.5 ± 4.0 , and 18.7 ± 4.9 mm Hg, respectively. A Kruskal-Wallis one-way analysis of variance showed that there was no statistically significant difference among the IOP readings in the three groups, with respect to GT (between groups $P = 0.870$) or the PPT (between groups $P = 0.823$). We also compared the performance of groups 2 and 3 using PPT and GT measurements: the Spearman correlation coefficient between PPT and GT was 0.91 for group 2 and 0.88 for group 3.

With the rating system as described previously, the mean \pm SD score for the ease of use of the PPT for home self-tonometry was 87.4 ± 16.3 . The mean \pm SD score for the ease of perceiving pressure phosphene was 78.0 ± 20.4 .

There were no complications or ocular injuries reported from use of the instrument in all our subjects.

DISCUSSION

There were no statistically significant differences in IOP measurements between PPT and GT in patients with glaucoma or ocular hypertension. First, the mean difference of readings by the two instruments was -0.24 mm Hg, which is clinically inconsequential in conventional IOP measurements. Second, the correlation coefficient of the PPT versus the GT was 0.91. This is better than the other study on the PPT versus the GT (0.71),⁸ the noncontact tonometer (NCT) versus GT (0.83),¹⁴ and Tonopen (Medtronic, Jacksonville, FL) versus GT (0.84).¹⁵ Third, we found that 86% of the differences were within ± 2.0 mm Hg and 91% of the differences were within ± 3.0 mm Hg. The Bland-Altman plot also revealed that the 95% limits of agreement between the PPT and GT was -3.38 to 2.90 mm Hg—better than Tonopen versus GT, for which the 95% limits of agreement lay between -5.37 and 6.99 mm Hg.¹⁵ Our data therefore suggest that the PPT can be an accurate instrument when compared with GT. It appears to be more accurate than NCT.

The reproducibility of both the GT and the PPT is considered to be good, as the within-subject CV for GT was 4.4% and that for the PPT was 7.3%. The latter is comparable to that of NCT (7.2%).¹⁶

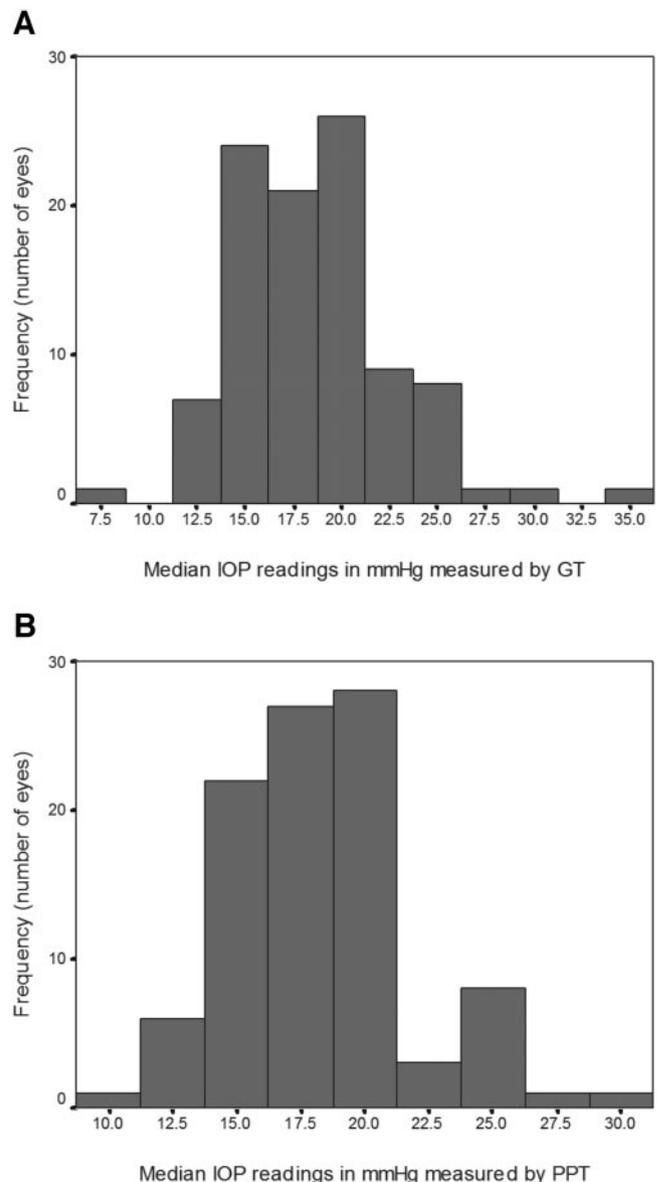


FIGURE 4. Distribution of IOP readings obtained by the GT (top) and PPT (bottom) at the week-1 visit.

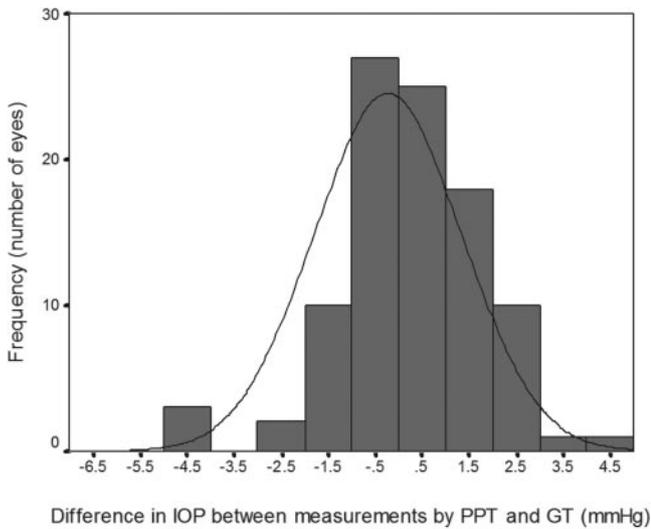


FIGURE 5. Distribution of differences in IOP readings between measurements by the PPT and GT, at the week-1 visit.

We studied how accurate the PPT was in detecting an increasing IOP during home self-tonometry, by asking patients to stop their glaucoma medications for 10 days. During this period, they measured their IOP with the PPT at home. There was a statistically significant increase in mean IOPs comparing the initial (17.9 mm Hg by GT and 17.6 mm Hg by PPT) versus day-10 visit (23.7 mm Hg by GT and 23.0 mm Hg by PPT; $P = 0.001$; Wilcoxon signed rank test) for both GT and PPT readings. The Spearman correlation of GT versus PPT was excellent (0.93–0.98). Thus, our data suggest that patients can accurately measure an elevation of their IOPs in self-tonometry by the PPT. We also found the PPT to be sensitive (92.3%) and specific (98.6%) in detecting an IOP level of more than 21 mm Hg. The results were comparable to a study on NCT in which the sensitivity was 100%, whereas specificity was 88% in detecting an increase in IOP of more than 21 mm Hg.¹⁷

We also evaluated the ease of use of the PPT at home. Using a simple scoring system, patients rated the PPT to be easy to

use (mean scores, 87.4 ± 16.3) and the phosphene easy to perceive (mean scores, 78.0 ± 20.4). Our data suggest that the PPT is acceptable to patients for home self-tonometry.

From the Bland-Altman plot (Fig. 6), it appears that there was a tendency to underestimate IOPs for GT readings more than 25 mm Hg. In the initial calibration of the PPT, linearity was good for the first 30% of the compression range of the instrument spring, and this corresponded to IOP ranges of 9 to 21 mm Hg.⁸ We thought that this might not necessarily lessen the value of the PPT as a tool for self-monitoring for three reasons. First, the role of the PPT is to detect an elevation of IOP above a target pressure, which in most, if not all patients with glaucoma, a value in the low to mid teens. Second, therefore, patients would have been expected to seek ophthalmic care before the self-measured IOP reached 25 mm Hg. Third, the sensitivity of the PPT in detecting an elevated IOP of more than 21 mm Hg was 92.3% and the specificity was 98.6%, both within a good range. Therefore, with proper expectation and patient education, the PPT may have a value for self-monitoring.

In recent years, it has become evident that central corneal thickness (CCT) is important in interpreting Goldmann applanation tonometry readings. A thick cornea gives rise to an artificially elevated GT reading. The optimal correction formula is yet undefined, though it was suggested that a correction of 1 mm Hg per 40- μ m deviation from 525 μ m can be made.¹⁸ Even if we take into account this effect, the mean central corneal thickness in our subjects (560.3 μ m) deviated for only 35 μ m, which translates into only 0.88 mm Hg of deviation in GT readings.

The PPT works on the principle of eyeball deformation, causing a tangential stretching of the retina and eliciting the sensation of light (phosphene). The PPT probe has the same application area as the Goldmann applanation tonometer prism.⁸ The application of force over a given area can be related through the Imbert-Fick's Law. In our experience, there were a few important potential sources of error that one should avoid during self-tonometry: First, the direction of self-application of the tonometer should be perpendicular to the superonasal eyelid covering the eyeball. The calibration of the PPT is only good when the force of application is along the axis

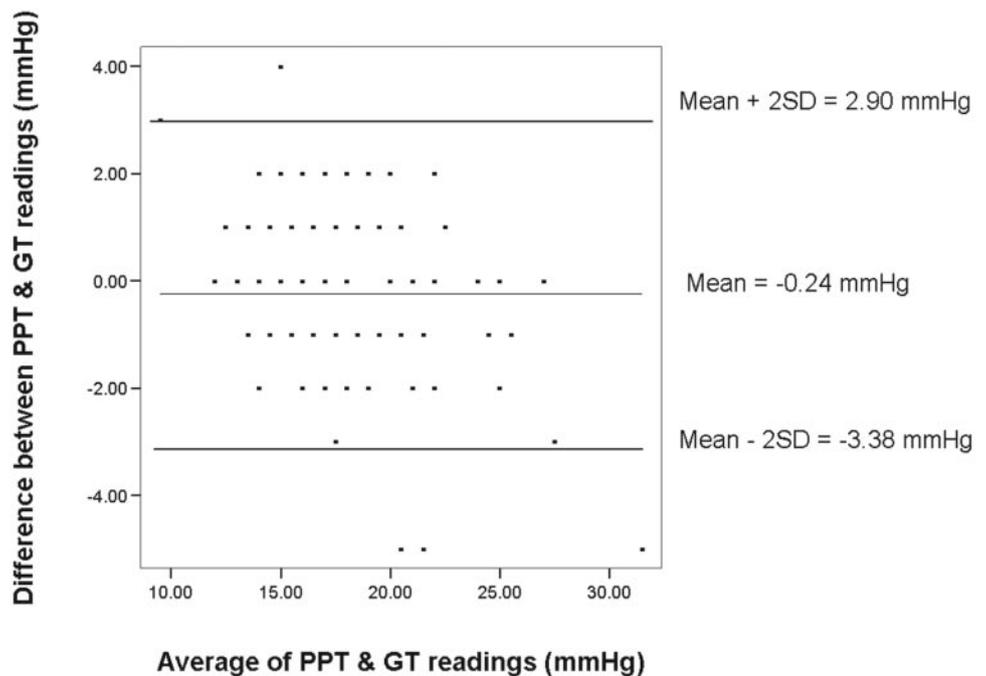


FIGURE 6. Bland-Altman plot of the difference between PPT and GT readings against the average of the two.

of the spring and allows the probe surface to be applied tangentially to the eyelid covering the eyeball. Second, patients should not make the end point too early, before they truly appreciated the phosphene (underestimating true IOP), or too late, when the phosphene is already well formed and enlarging on excessive pressures (overestimating true IOP). We emphasize that for an accurate reading, the desired endpoint should be the very first moment that the patient clearly perceives a phosphene. From our experience, some patients may need to be reminded of this intermittently to avoid those errors.

Although the majority of subjects (74.5%, group 2) saw the glowing rim of pressure phosphene, a significant proportion (22.5%, group 3) did not. The reason for this phenomenon is uncertain. Our analysis did not reveal any statistically significant difference in age and IOP measured by the GT and the PPT between these two groups. The performance in using the PPT was also comparable in both groups.

There were no ocular injuries or complications detected arising from the use of the PPT in our study. Theoretically, the PPT is noninvasive because it requires no direct contact with the eyeball. The duration of application of the PPT onto the eyelid is in terms of seconds. Patients should be educated about the proper technique for using the PPT, and should be warned to withdraw the instrument as soon as a phosphene is perceived and that a further push is neither required nor desirable, to avoid any unnecessary self-inflicted damage. We recognize the need to collect further data on the safety of the PPT.

We excluded patients with previous ocular surgery, because we do not yet know how a possible change of scleral rigidity after operations might affect the measurements. We recognize that patients may have been excluded who had more advanced diseases and who may have been more likely to have trabeculectomy or other ocular surgery performed. Our recruited subjects with glaucoma appeared to have less advanced disease, as 51.5% of them have not yet had glaucomatous field loss, with overall mean Snellen best corrected visual acuity at 0.73. Further study to investigate the performance of the PPT in patients with advanced disease appears warranted.

The patients recruited into this study performed self-tonometry well with the PPT. They were relatively young, with a mean age of 54.3 ± 12.6 years. We anticipated that patients with problems in coordination, (e.g., arthritis of the upper limb, significant hand tremor), which may be more common in the elderly, would have difficulty with this self-tonometry. Further study on a wider age range of patients appears warranted.

Future study on the diurnal curves obtained by the PPT compared with other instruments will better validate its usefulness for home self-tonometry. In this study we have not addressed the value of home tonometry in the management of glaucoma. We envisage that the true value of self-monitoring of IOP with the PPT can only be determined with a randomized controlled trial to see whether patients with glaucoma using the PPT for home tonometry will have better long-term outcomes than those who do not.

In conclusion, to our knowledge, this is the first study of self-tonometry with the PPT in patients with glaucoma. Our results suggest that self-tonometry with the PPT by patients with glaucoma or ocular hypertension, with proper training and technique, is accurate and reproducible up to at least 25 mm Hg. The PPT is a sensitive and specific method for detect-

ing an elevation of IOP to more than 21 mm Hg. Because patients are expected to seek ophthalmic care before the self-measured IOP reaches 25 mm Hg, the PPT will be of value for self-monitoring. Patients rated the PPT to be satisfactory and easily comprehensible for home use. The PPT is relatively inexpensive and portable and requires no or topical anesthesia or direct contact with the eyeball. It may have potential as an instrument for home self-tonometry.

Acknowledgments

The authors thank John K. H. Chua, Barry Y. M. Yeung, Philip W. C. Ng, Doris W. F. Yick, and Arthur C. K. Cheng for assistance in recruiting patients for the study.

References

1. de Alva M, Jervell J. Self monitoring improves quality of life and prognosis of people with diabetes. *Br Med J.* 1997;315:184-185.
2. Jensen AD, Maumenee AE. Home tonometry. *Am J Ophthalmol.* 1973;76:929-932.
3. Asrani S, Zeimer R, Wilensky J, et al. Large diurnal fluctuations in intraocular pressure are an independent risk factor in patients with glaucoma. *J Glaucoma.* 2000;9:134-142.
4. Boles Carenini B, Brogliatti B, Tonetto C, Renis E. The Pulsair-Keeler non-contact tonometer in self-tonometry: preliminary results. *Int Ophthalmol.* 1992;16:295-297.
5. Kupin TH, Shin DH, Juzych MS, Olivier MM, Kim C. Use of Tono-Pen for long-term home tonometry. *Am J Ophthalmol.* 1993;116:643-644.
6. Zeimer RC, Wilensky JT, Gieser DK, Welch DB, Mori MT, Kahanic D. Application of a self-tonometer to home tonometry. *Arch Ophthalmol.* 1986;104:49-53.
7. Wilensky JT, Gieser DK, Mori MT, Langenberg PW, Zeimer RC. Self-tonometry to manage patients with glaucoma and apparently controlled intraocular pressure. *Arch Ophthalmol.* 1987;105:1072-1075.
8. Fresco BB. A new tonometer: the pressure phosphene tonometer. *Ophthalmology.* 1998;105:2123-2126.
9. Jonas JB, Budde WM, Panda-Jonas S. Ophthalmoscopic evaluation of the optic nerve head. *Surv Ophthalmol.* 1999;43:293-320.
10. Thomas R, Paul P, Muliylil J. Use of pattern standard deviation instead of corrected pattern standard deviation in Anderson's criteria. *J Glaucoma.* 2000;9:480-482.
11. Kass MA. Standardizing the measurements of intraocular pressure for clinical research: guidelines from the eye care technology forum. *Ophthalmology.* 1996;103:183-185.
12. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;1:307-310.
13. Bland JM, Altman DG. Statistics notes: measurement error. *Br Med J.* 1996;313:744.
14. Shields MB. Diagnostic and surgical techniques: the non-contact tonometer—its value and limitations. *Surv Ophthalmol.* 1979;24:211-219.
15. Frenkel RE, Hong YJ, Shin DH. Comparison of the Tono-pen to the Goldmann applanation tonometer. *Arch Ophthalmol.* 1988;106:750-753.
16. Aakre BM, Doughty MJ, Dalane OV, Berg A, Aamodt O, Gangstad H. Assessment of reproducibility of measures of intraocular pressure and central corneal thickness in young white adults over a 16-h time period. *Ophthalmic Physiol Opt.* 2003;23:271-283.
17. Vernon SA. Non-contact tonometry in the postoperative eye. *Br J Ophthalmol.* 1989;73:247-249.
18. Asian Pacific Glaucoma Guidelines. Sydney, Australia: South East Asia Glaucoma Interest Group (SEAGIG); 2004:15.