Measurements of Intraocular Pressure by Goldmann Tonometry, Tonopen XL, and the Transpalpebral Tonometer, TGDc-01, After Penetrating Keratoplasty: A Comparative Study

Gabi Shemesh, MD, Michael Waisbourd, MD, David Varssano, MD, Adi Michaeli, MD, Moshe Lazar, MD, and Shimon Kurtz, MD

Purpose: The aim of this study was to compare intraocular pressure (IOP) measurements obtained by Goldmann tonometry (GT), the Tonopen XL, and a new transpalpebral tonometer, TGDc-01, in eyes that had undergone penetrating keratoplasty (PKP).

Methods: IOP was measured in post-PKP eyes by means of GT, Tonopen XL, and TGDc-01. Central corneal thickness measurements were also obtained for all eyes.

Results: Forty-five eyes of 43 patients were enrolled in the study. The mean IOP difference (±SD) was 20.42 ± 5.83 mm Hg between GT and Tonopen and 3.20 ± 7.55 mm Hg between GT and TGDc-01. The correlation coefficient was 0.84 between GT and Tonopen XL (P, 0.001) and 0.71 between GT and TGDc-01 (P < 0.001). Overall 2-way analysis of variance between the means showed no significant differences between the 3 devices (P = 0.077).

Conclusions: A closer agreement was found between GT and Tonopen XL in post-PKP eyes. TGDc-01 yielded lower IOP readings than the other 2 devices. It remains uncertain whether this new transpalpebral tonometer is simply inaccurate or whether avoiding contact with the corneal graft by measuring IOP through the eyelid enables it to provide more accurate IOP readings than those obtained by transcorneal techniques.

Key Words: intraocular pressure, Goldmann, Tonopen, TGDc-01, transpalpebral tonometer, penetrating keratoplasty

Measuring intraocular pressure (IOP) after penetrating keratoplasty (PKP) is essential, given that up to 30% of patients who undergo the procedure may have elevated IOP, risking both the optic nerve and the corneal graft. The measurement of IOP after PKP is influenced by graft size, postsurgical astigmatism, and by the presence of corneal edema. Goldmann tonometry (GT, Haag-Streit, Koeniz, Switzerland) is currently considered the gold standard for measuring IOP in the normal cornea. Because its accuracy is influenced by corneal shape and central corneal thickness (CCT), however, it may be less precise in post-PKP eyes. Tonopen XL (Reichert, Inc, Depew, NY) is a portable digital tonometer, which measures IOP over a small corneal contact area. The smallplanation area seems suitable for measurements of IOP in irregular corneas, but Tonopen seems to either overestimate or underestimate IOP in an unpredictable manner when compared with GT. TGDc-01 (Ryazan State Instrument Making, Ryazan, Russia) is a new digital transpalpebral tonometer whose accuracy in measuring IOP is a matter of controversy in the literature. We designed the current study to compare the IOP measurements in post-PKP eyes of the 2 main transcorneal methods in current clinical use for measuring IOP (GT and Tonopen XL) with those of the transpalpebral method (TGDc-01).

Materials and Methods

Forty-five eyes of 43 patients after PKP were included in our study. PKP had been performed because of various pathologies. All the study patients were attending the outpatient Cornea Clinic of the Tel Aviv Sourasky Medical Center for post-PKP follow-up visits. The routine eye examination included the measurement of IOP using all 3 devices, GT, Tonopen XL, and TGDc-01, for each patient.

The order of the tests was Tonopen, GT, and TGDc-01. Two measurements were obtained for each device, and the average of the 2 was recorded. All the instruments were calibrated regularly according to the manufacturer’s instructions. For Tonopen XL measurements, a disposable latex membrane was placed on the transducer for each patient before measurement. The eyes were instilled with 1 drop of oxybuprocaine hydrochloride 0.4%. The operator touched the cornea with the portable pen tip several times until a reading was digitally displayed. For GT measurements, the eyes were instilled with a drop of oxybuprocaine hydrochloride 0.4% and by strip fluorescein dye, followed by cornealplanation measurement. IOP was measured without viewing the dial. The IOP in...
eyes with irregular astigmatism was recorded in the steepest and the flattest meridian using GT, and the mean result was recorded. For the TGDC-01 measurements, the patients were examined with the head leaning back 45 degrees above the horizon and while they were sitting in a chair. They were asked to look downward, and the tonometer was placed on the upper eyelid. By pushing a button, a metal plate with a known weight deformed the sclera through the eyelid. This scleral indentation was digitally analyzed into an IOP reading. After these IOP measurements were performed, the CCT was measured using the Sonogage Corneo-Gage Plus ultrasonic pachymetry (Sonogage, Inc, Cleveland, OH) 3 times and the values were averaged. The study was performed with the approval of the institutional ethics committee and informed consent was obtained from each participant.

Statistics

The data were analyzed using 2-way analysis of variance (ANOVA), and the Pearson correlation value was calculated. The findings were evaluated for each technique individually and by plotting differences against the means for ANOVA. Difference histograms were plotted to establish the distribution. All calculations were performed using SPSS statistical software.

RESULTS

A total of 45 eyes of 43 post-PKP patients enrolled in our study. They included 26 women (58%), and the mean age of the entire cohort was 67.2 years (range 22–92 years). IOP measurements were obtained between 6 months and 3 years after surgery. Table 1 lists the IOPs as measured by each of the 3 tonometers. IOP measured by GT was taken as the standard for comparison. The mean difference of IOPs was −0.42 ± 5.83 mm Hg between GT and Tonopen XL and 3.20 ± 7.55 mm Hg between GT and TGDC-01.

Table 2 compares IOP measurements within ±2, ±3, and ±4 mm Hg by GT versus those by Tonopen XL and TGDC-01. Figure 1 displays the difference in the histograms of GT versus Tonopen XL and TGDC-01. The correlation coefficient was 0.84 (P < 0.001) between GT and Tonopen XL and 0.71 (P < 0.001) between GT and TGDC-01 (Fig. 2). The difference between these 2 correlation coefficients was statistically significant (P = 0.05). The results of an overall 2-way ANOVA for comparing the IOP mean differences between the 3 devices were not significant (P = 0.077, power = 0.509).

Pachymetric measurements ranged from 441 to 913 μm (mean 593 ± 94 μm). For all tonometers, the higher the CCT, the higher was the measured IOP (Fig. 3). Seven of the 45 corneas (15.6%) were edematous. Bland–Altman plots present better agreement between Tonopen XL and GT when compared with TGDC-01 and GT (Figs. 4, 5, respectively).

DISCUSSION

Glaucoma is prevalent after PKP and poses a challenge in terms of both diagnosis and treatment. Moreover, glaucoma is the second leading cause of graft failure after graft rejection. The etiology of glaucoma after PKP is multifactorial and is probably related to the distortion of the angle with collapse of the trabecular meshwork, suturing techniques, postoperative inflammation, and the formation of peripheral anterior synechiae. Measuring IOP in transplanted eyes, although often tricky, is of utmost importance to begin treatment, when necessary, as early as possible.

We designed the current study to compare 2 widely used transcorneal methods for measuring IOP after PKP with a novel transpalpebral method that was recently introduced for commercial use. The GT was the gold standard for our study, and its results were compared with those of the Tonopen XL and the new TGDC-01 tonometer. GT can be used to measure IOP in post-PKP eyes if the graft surface is fairly smooth, the epithelium is intact, and the mires are fairly regular. In the early postoperative period, however, when the corneal surface is irregular, IOP can usually (and preferably) be measured with Tonopen. In order for GT to obtain an accurate reading in eyes suffering from marked corneal astigmatism, 2 pressure readings taken 90 degrees apart can be averaged. Despite these post-PKP difficulties, GT continues to be the gold standard for IOP measurements in these eyes.

The results of our study revealed closer agreement between GT and Tonopen XL and less agreement between GT and TGDC-01 readings. The mean IOP difference was −0.42 ± 5.83 mm Hg for GT and Tonopen XL, with 30 of 45 measurements (67%) within ±4 mm Hg. This difference remains within the reproducibility of GT, which ranges from 2 to 4 mm Hg in normal eyes. On the other hand, GT and TGDC-01 exhibited less agreement, with a mean IOP difference of 3.20 ± 7.55 mm Hg and only 24 of 45 measurements (53%) within ±4 mm Hg. Two-way ANOVA for comparing the IOP mean differences for the 3 devices was not significant (P = 0.77).

Several earlier studies compared Tonopen XL and GT after PKP and reported equivocal results. Rootman et al concluded that the Tonopen is accurate in monitoring IOP in those eyes in which GT is not useful. Rao et al found a mean IOP difference of 0.14 mm Hg between GT and Tonopen.

### Table 1. Mean IOP Readings Using the 3 Tonometers in Eyes That Had Undergone PKP

<table>
<thead>
<tr>
<th>Tonometer</th>
<th>No. Eyes</th>
<th>Mean (mm Hg)</th>
<th>SD (mm Hg)</th>
<th>Range (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT</td>
<td>N = 45</td>
<td>19.22</td>
<td>10.76</td>
<td>4–54</td>
</tr>
<tr>
<td>Tonopen XL</td>
<td>N = 45</td>
<td>19.64</td>
<td>9.51</td>
<td>6–49</td>
</tr>
<tr>
<td>TGDC-01</td>
<td>N = 45</td>
<td>16.02</td>
<td>7.34</td>
<td>5–39</td>
</tr>
</tbody>
</table>

### Table 2. Comparison of Percent Measurements Within ±2 to ±4 Mm Hg Between Tonopen XL, TGDC-01, and the GT

<table>
<thead>
<tr>
<th>Tonometer</th>
<th>Within ±2 mm Hg</th>
<th>Within ±3 mm Hg</th>
<th>Within ±4 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonopen XL</td>
<td>44 (20/45)</td>
<td>62 (28/45)</td>
<td>67 (30/45)</td>
</tr>
<tr>
<td>TGDC-01</td>
<td>40 (18/45)</td>
<td>49 (22/45)</td>
<td>53 (24/45)</td>
</tr>
</tbody>
</table>

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Geyer et al., however, reported that the Tonopen XL overestimates IOP with no consistent pattern. Our findings support the view that Tonopen XL is a helpful tool for measuring IOP when GT is not applicable.

To the best of our knowledge, this is the first study to compare GT and TGDC-01 in post-PKP eyes. TGDC-01 had been evaluated for application in normal eyes, and some studies found it to be useful: Sandner et al.7 considered it as a helpful screening tool when GT is not applicable, having found a mean difference of 0.71 ± 2.467 mm Hg and 66.4% of their measurements within ±2 mm Hg; Nesterov et al.9 also found the new tonometer sufficiently accurate for clinical purposes, with 90.2% of their measurements within ±2 mm Hg. Other groups, however, refuted its reliability: Losch et al.8 did not find TGDC-01 reliable (a mean difference in IOP of 3.7 ± 4.06 mm Hg), and Troost et al.16 reported a deviation of more than ±3 mm Hg in 38% of the tested eyes. The latter 2 studies were supported by several others17–19 that also did not encourage the use of the new tonometer as a screening device.

The current study has a number of drawbacks: IOP measurements were not obtained in a randomized manner, and so the mere repetition of tests might have influenced the IOP measurements. Because we also included failed grafts in our study cohort (7 of 45, 15.6%), IOP measurements by applanation tonometry might have been influenced by these edematous corneas. Moreover, the measurement obtained by each tonometer only estimates the true IOP. Further cannulating manometric studies are warranted to determine the genuine deviations of the tonometers from the true IOP.

Our study showed that the TGDC-01 device measured the lowest IOP of post-PKP eyes. There are several explanations for this. First, it is possible that the new tonometer is not sufficiently accurate for any IOP measurements, even in normal eyes, as mentioned above. Second, the TGDC-01 device may underestimate IOP with increasing IOP levels, as suggested by Troost et al.20 Third, it should be kept in mind that measuring IOP by GT is influenced by CCT.21 In general, the
thicker the cornea, the higher the IOP measured by GT.\textsuperscript{22} It is possible that in addition to the CCT influence on transcorneal IOP measurements per se, the transplanted cornea itself may become stiffer because of changes resulting from the harvesting and transplantation processes, thus causing falsely elevated IOP measurements when measured by a transcorneal method. Theoretically, transpalpebral measurements of IOP may bypass the cornea and reflect a more genuine measurement than a transcorneal method. Manometric studies would be needed to investigate this possibility. Our study also demonstrated that CCT influenced the measured IOP, even when the cornea was bypassed by the transpalpebral tonometer, and demonstrated linear relations between CCT and IOP for all tonometers (Fig. 3).

In conclusion, the transcorneal IOP measurements obtained by GT agreed more closely with those obtained by Tonopen XL than by TGDc-01. The transpalpebral tonometer (TGDc-01) exhibited comparatively lower IOP readings, which may be attributed to an allegedly low reliability of the device. Alternatively, the fact that the TGDc-01 tonometer bypasses the cornea may reflect more genuine IOP readings of transplanted eyes. Further manometric studies are warranted to establish the validity of the measurements obtained by the new device in post-PKP eyes.

**FIGURE 4.** Bland–Altman plot comparing between Tonopen XL and GT.

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**REFERENCES**


