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ORIGINAL ARTICLE

Comparison of intraocular pressure measurement using Goldmann, tonopen, and non-contact tonometers in patients with penetrating keratoplasty

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Abstract

Purpose: The purpose of the study was to compare intraocular pressure (IOP) values measured by Goldmann applanation tonometer (GAT) with IOP values measured by Tonopen and non-contact tonometer (NCT) in patients with penetrating keratoplasty (PKP).

Methods: Eighty-eight eyes of 72 patients who underwent PKP surgery were included in the study. Detailed ophthalmological examination was performed. Central corneal thickness (CCT) was measured with an ultrasonic pachymeter and recorded. IOPs were measured with GAT, Tonopen, and NCT. Data were analyzed statistically.

Results: The mean age of the patients was 56.2±14.7 years; the mean duration of PKP was 62.5±51.6 months. The mean CCT was 561±65µm. Mean IOP values were 15.4±3.0 with GAT, 12.8±4.5 with Tonopen, and 11.7±4.6 mmHg with NCT ($p<0.001$). There was a difference between IOP values between GAT and Tonopen ($p<0.001$) and between GAT and NCT ($p<0.001$), while there was no difference between Tonopen and NCT IOP values ($p=0.06$). There was no correlation between IOP values measured in all three methods and CCT ($p>0.05$). Both Tonopen and NCT IOP values were correlated with GAT IOP values ($r=0.424$, $p<0.001$; $r=0.374$, $p<0.001$).

Conclusion: In patients with PKP, IOP values measured with GAT are higher than IOP values measured by Tonopen and NCT. GAT remains the most established method of IOP measurement in clinical practice, yet it has significant limitations in corneas that deviate significantly from normal values, as is the case in PKP. During follow-up, measurements can be taken with the same device suitable for the structure of the eye. Due to structural differences, if the IOP value measured with a device is too high or too low in patients with PKP, the IOP value should be measured with other devices, and the results should be compared.

Keywords: Central corneal thickness, goldmann applanation tonometer, non-contact tonometer, penetrating keratoplasty, tonopen.

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Accurate measurement of intraocular pressure (IOP) is crucial for achieving and maintaining surgical success following penetrating keratoplasty (PKP).[1] Untreated post-operative pressure elevations can lead to damage to the optic nerve, an increase in endothelial cell loss, and graft failure.[2] In some studies, IOP elevations after PKP have been reported at high rates ranging from 14% to 78%.[3,4] Most IOP measurement devices are designed for "normal" corneas, and the accuracy of these methods may be questioned due to the new and different corneal formation that occurs after corneal transplantation, which involves altered corneal morphology and mechanics.

In clinical practice, Goldmann applanation tonometer (GAT) is generally accepted as the "gold standard" for measuring IOP; however, its use as the gold standard for measuring IOP after keratoplasty has not yet been widely accepted. Despite its widespread use, GAT has significant limitations. Measurements are affected by factors such as central corneal thickness (CCT, it is calibrated for 520 µm), corneal irregularities, accumulation of fluorescent meniscus in sutures, and direct or indirect pressure on the globe (including eyelid squeezing and Valsalva maneuvers). Corneal scarring or edema can also affect corneal rigidity and measurements.[5] Corneal astigmatism is also a significant source of error in GAT, and previous studies have shown that corneal astigmatism can affect measured IOP by a ratio of 0.2–0.67 mmHg/diopter. PKP corneas typically exhibit varying levels of astigmatism, have a typically thicker pachymetry than 520 µm, and may have subclinical edema, so GAT measurements are affected after PKP. In addition, early GAT is not recommended after PKP due to the possibility of damage to the transplanted cornea's epithelium.[6]

Tonopen AVIA is a portable digital tonometer that measures IOP on a small corneal contact area. It is an electronic handheld device that uses the MacKay-Marg tonometry principle.[7] The small application area is suitable for measuring IOP in irregular corneas. Its portability, compactness, and calibratability are advantages that minimize user bias and provide a digital reading. It has good repeatability and capacity for use in abnormal corneas. Compared to GAT (3.06 mm), Tonopen has a smaller application area (1.00 mm).[7,8] When compared to GAT, Tonopen appears to be suitable for IOP measurements in irregular corneas with small applanation areas, but in some studies, Tonopen can measure IOP higher or lower than expected. Tonopen has also been shown to measure IOP higher in thicker corneas and lower than expected in thinner corneas.[9-11]

Non-contact tonometer (NCT) exposes the cornea to a linearly increasing airflow for milliseconds, at which point a light beam is reflected from the newly flattened surface. The time it takes to look at the cornea and the amount of light reflected from the corneal surface is used to calculate IOP. The main advantage of NCT is that the device does not require direct contact with the cornea, and, therefore, does not require anesthetic drops, is less prone to practitioner errors, and has a probe that does not require cleaning. Studies have shown agreement between values measured with NCT and GAT in normal corneas.[12]

The aim of this study is to evaluate the agreement between IOP measurements obtained with GAT, Tonopen, and NCT in patients who have undergone PKP surgery and to examine the effect of CCT.

Materials and Methods

The study was conducted between January 01, 2020, and May 30, 2020. Eighty-eight eyes of 72 patients who underwent PKP surgery and were followed up in our cornea unit were included in the study. Patients with post-operative stromal edema resolution time, restoration of corneal epithelial architecture, and typically stabilized corneal astigmatism caused by sutures taking time to stabilize were included if the surgical period was 3 months or more after surgery. Patients with scars, keratitis, graft edema, or rejection that could affect IOP measurement, nystagmus, or inability to cooperate during the examination due to old age, patients with mental retardation, and patients using contact lenses were excluded from the study. The study was approved by the Ethics Committee on January 13, 2021 with 02 decision number. In accordance with the principles of the Helsinki Declaration during the study period, informed consent was obtained from all patients.

All patients underwent ophthalmological examination and best-corrected visual acuities were measured. Biomicroscopic examination was performed with a slit lamp. IOP measurements were taken using a NCT, Tonopen, and GAT, respectively. Measurements were repeated 3 times, and the means were taken. Measurements with each device were performed by different individuals and the results were masked. All devices were regularly calibrated according to the manufacturer's instructions.

For GAT measurements, after applying 0.5% proparacaine (Alcain; Alcon Laboratories, Inc., Fort Worth, TX, USA) and strip fluorescein dye to the eyes, IOP was measured by the practitioner without the numerical dial being visible. Care

was taken to ensure that the tonometer head did not come into contact with the cornea for longer than necessary. Measurements were taken from eyes with a smooth graft surface, intact epithelium, and fairly regular sutures.

For Tonopen AVIA (TPA, Reichert Inc. NY, USA) measurements, the manufacturer's recommended latex cover was used. The transducer was placed for each patient before measurement. Anesthesia was provided by applying a drop of 0.5% proparacaine to the eye to be measured. The Tonopen was placed on the graft several times until a digital reading was displayed.

CT-20 NCT (TOPCON Corp, Tokyo, Japan) was used for NCT measurements. Patients were seated comfortably, and the forehead and chin were placed in contact with the relevant platform of the NCT for automatic measurement. CCT was measured using an ultrasonic pachymeter PACSCAN 300P USP device (Sonomed Inc, Lake Success, NY, USA).

Statistical Analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) 21.0 (SPSS Inc., Chicago, IL) software. Data obtained by taking the means of all measurements were recorded as mean±standard deviation. The distribution of data within groups was evaluated using the Shapiro–Wilk test. Analysis of variance was used to compare values between groups and independent t-tests were used for pairwise comparisons. Relationships between dependent variables were analyzed using Pearson correlation analysis. Differences in IOP distribution between measurement methods were analyzed using the Bland-Altman method. A $p<0.05$ was considered statistically significant.

Results

The mean age of the patients was 56.2±14.7 years, and the mean time since PKP surgery was 62.5±51.6 months. The mean CCT was 561±65µm. The mean IOP values were 15.4±3.0 mmHg with GAT, 12.8±4.5 mmHg with Tonopen, and 11.7±4.6 mmHg with NCT ($p<0.001$). The demographic characteristics of the patients are summarized in Table 1. In patients who underwent PKP, IOP values measured with GAT were higher than those measured with Tonopen and NCT. IOP values measured with GAT were 2.5 mmHg higher than those measured with Tonopen and 3.7 mmHg higher than those measured with NCT. IOP values measured with Tonopen were 1.2 mmHg higher than those measured with NCT. In pairwise comparisons, significant differences were found between GAT and Tonopen ($p<0.001$) and between GAT and NCT ($p<0.001$), but there was no significant difference between Tonopen and NCT IOP values ($p=0.06$).

Table 1. Demographic characteristics of the patients

Number of patient/number of eye (n)	72/88
Gender (female/male)	28 (39%)/44 (61%)
Age (year)	56.2±14.7
PKP time (months)	62.5±51.6
CCT (µm)	561±65µm
IOP (mmHg)	
GAT mean (min-max)	15.4±3.0 (7–22)
Tonopen mean (min-max)	12.8±4.5 (5–25)
NCT mean (min-max)	11.7±4.6 (4–25)

PKP: Penetrating keratoplasty; CCT: Central corneal thickness; IOP: Intraocular pressure; GAT: Goldmann applanation tonometer; NCT: Non-contact tonometer.

The distribution of IOP differences measured with both methods was between ±8.4 mmHg using the Bland–Altman analysis for GAT and Tonopen (Fig. 1), between ±8.8 mmHg for GAT and NCT (Fig. 2), and between ±11.4 mmHg for Tonopen and NCT (Fig. 3).

There was no correlation between IOP values measured with all three methods and CCT ($p>0.05$). IOP values measured with GAT were correlated with both Tonopen and NCT IOP values ($r=0.424$, $p<0.001$; $r=0.374$, $p<0.001$). There was no significant correlation between Tonopen and NCT IOP values ($r=0.201$, $p=0.061$).

Discussion

The incidence of elevated IOP and glaucoma development after PKP varies between 5.3% and 47.9%. The etiology of glaucoma after PKP is multifactorial and likely related to the collapse of the trabecular meshwork, post-operative steroid

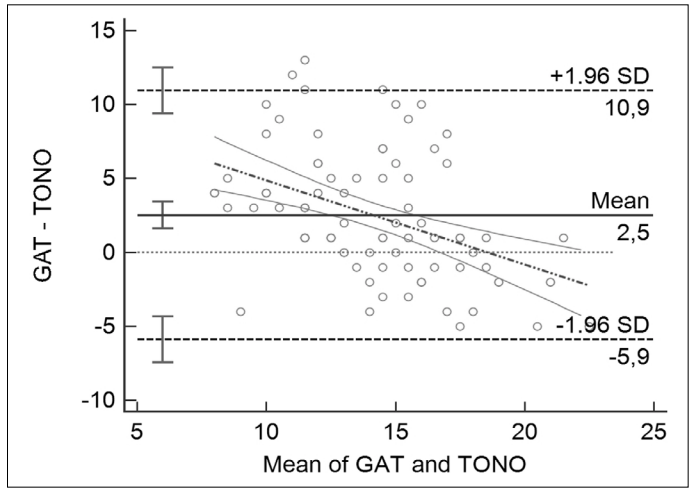

Fig. 1. Distribution of intraocular pressure differences measured by Goldmann applanation tonometer and Tonopen by Blant and Altman Analysis. The 95% confidence interval is shown with dashed lines. The differences obtained with both methods were found between ± 8.4 mmHg.

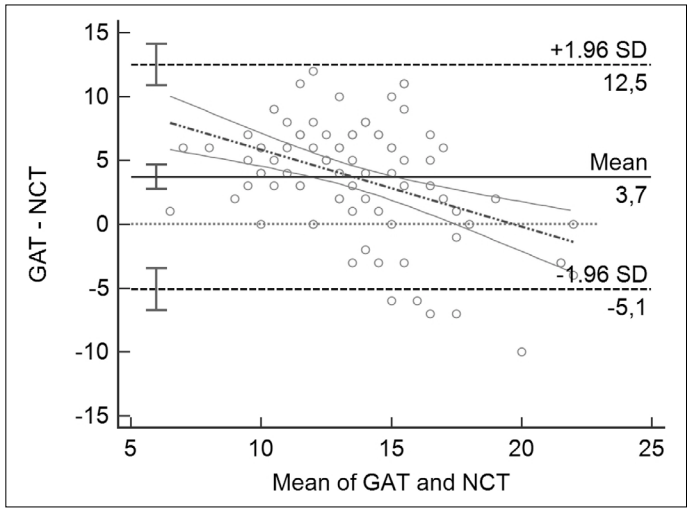

Fig. 2. Distribution of intraocular pressure differences measured by Goldmann applanation tonometer and non-contact tonometer by Blant and Altman Analysis. The 95% confidence interval is shown with dashed lines. The differences obtained with both methods were found to be within ± 8.8 mmHg.

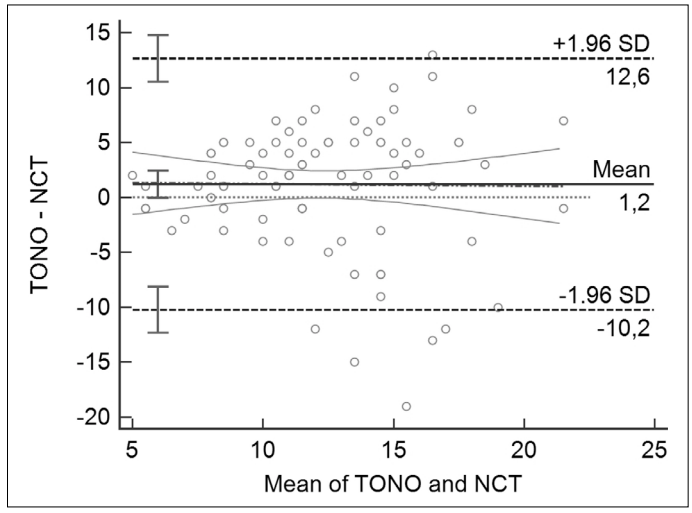

Fig. 3. Distribution of intraocular pressure differences measured by Tonopen and non-contact tonometer by Blant and Altman Analysis. The 95% confidence interval is shown with dashed lines. The differences obtained with both methods were found between ± 11.4 mmHg.

use, suture techniques, post-operative inflammation, and angle disruption due to peripheral anterior synechiae.[13,14] Therefore, regular measurement and monitoring of IOP during the post-operative period is necessary. To accurately measure IOP in PKP patients using the gold standard GAT for glaucoma patients, the mires must be very regular. However, measurements can be negatively affected during the post-operative period due to significant differences in average graft thickness and steeper or flatter keratometry values. Therefore, an ideal method is needed for measuring IOP.

In studies conducted on healthy eyes, it has been found that Tonopen measures IOP correctly according to GAT when IOP is between 10 mmHg and 19 mmHg, but it is prone to measuring higher when IOP is below 9 mmHg and lower when IOP is above 30 mmHg.[15] Rootman et al.[16] concluded that Tonopen is accurate in monitoring IOP in eyes where GAT is not useful. Rao et al.[17] found an average difference of 0.14 mmHg in IOP measurements between GAT and Tonopen. In Yildiz et al.'s[18] study of 34 patients who underwent descemet membrane endothelial keratoplasty IOP values measured with GAT, Tonopen, and Pascal dynamic contour tonometry (PDCT) were compared, and measurements with GAT were found to be lower than the other two devices. The difference between GAT and Tonopen was found to be statistically significant. IOP values obtained with all three devices did not show a statistically significant correlation with CCT values. It has been suggested that all three measurement techniques may be practical in post-surgical examinations, but IOP should be measured with the same device during patient follow-up.

In a 31-case series where Chou et al.[19] compared four different IOP measurement methods at an average of 27 weeks post-PKP, they found that Tonopen measured IOP values 0.57 mmHg lower than GAT, and they found a significant correlation between the two measurement methods. The authors stated that Tonopen could be an alternative to GAT measurements in PKP eyes. In addition, they found no effect of CCT on GAT, Tonopen, PDCT, and ocular response analyzer (ORA) measurements in their comparison of four different measurement methods after PKP. In the study by Fabian et al.,[20] Tonopen measurements were 1.7 mmHg higher than GAT and there was a significant correlation between the two measurement methods. They also reported that all measurement methods after PKP, including GAT, Tonopen, i-care, and ORA, were not affected by CCT and emphasized that CCT is less effective than corneal hysteresis and corneal resistance factors in terms of biomechanics. In our study, although there was a significant agreement between the two devices, the difference in measurements was 2.5 mmHg. We think that the higher the number of patients in our study, the lower the mean CCT and the later post-PKP measurement could be effective in the high difference between the measurements.

Other factors that can affect IOP measurements after PKP include suture presence and corneal astigmatism. Chou et al.[19] found that IOP measured by GAT, Tonopen, and ORA did not show a significant correlation with corneal astigmatism in the early post-operative period if sutures

were still present and that IOP could be measured independently of corneal astigmatism, possibly related to biomechanical properties of the graft-host interface. Similarly, Fabian et al.[20] found a correlation between GAT and Tonopen measurements in both sutured and unsutured PKP eyes. In our study, cases in which corneal mires were affected in GAT, especially due to high astigmatism, were not included in the study. One limitation of our study is the lack of a subgroup including suture presence and corneal astigmatism in terms of PKP duration. Such a subgroup could have analyzed the effect of suture-related corneal astigmatism on measurements and changes in corneal biomechanics at the graft-host interface.

The structure of the graft after PKP can affect IOP measurements too. Yeh et al.[21] determined that IOP values measured with NCT and Tonopen were higher than GAT and the agreement between the devices was low in a 27-case series where graft failure or rejection-related corneal edema developed after PKP. In our study, factors that could affect IOP measurement after PKP, such as scar, graft rejection, graft failure, and edema, were excluded, and our results evaluated measurements in healthy grafts.

Studies comparing NCT and GAT in healthy and glaucomatous eyes have shown inconsistent results regarding their agreement. Some studies report statistically significant differences between the two methods, while others do not find any significant differences. Factors such as CCT, tear film distribution, age differences, Valsalva maneuver, and calibration of the devices have been proposed as reasons for these discrepancies.[22,23] There are limited studies comparing GAT and NCT measurements after PKP. Lisle and Ehlers[24] reported a 0.96 mmHg difference between GAT and NCT measurements in a study of 42 PKP patients and found no correlation between these measurements and CCT, astigmatism, or graft diameter. However, in our study, the difference between GAT and NCT measurements was higher. This could be due to differences in the number of patients included and their corneal thicknesses in the two studies.

In most studies, including ours, IOP values measured by all measurement methods have been shown to be statistically independent of CCT. However, some studies have shown a significant negative correlation between corneal graft thickness and IOP measured by PDCT.[25,26] The lack of correlation between IOP and CCT in PKP studies is attributed to changes in the graft-host interface and corneal biomechanics.[27]

Conclusion

The most accurate method for measuring IOP after keratoplasty is currently unknown. While GAT is considered the gold standard for normal corneas, other measurement methods may be appropriate for keratoplasty patients. Studies comparing different measurement methods for their comparable results are ongoing. Devices with clinically acceptable limits of IOP differences can be used to monitor keratoplasty patients. However, it is recommended to use the same device for pre- and post-operative follow-up and to use different devices for very low or high IOP measurements. At the same time, structural and functional tests should be performed in the follow-up of patients with PKP to diagnose glaucoma and detect progression.

Ethics Committee Approval: The study was approved by the Ethics Committee on January 13, 2021 with 02 decision number. In accordance with the principles of the Helsinki Declaration during the study period, informed consent was obtained from all patients.

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