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Original Article

Agreement among Goldmann Applanation Tonometer, Easyton Transpalpebral Tonometer, Tonopen, and Icare in Patients with Keratoconus

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Abstract

Objectives: The objective of the study is to evaluate the agreement between Goldmann applanation tonometer (GAT) and Easyton transpalpebral tonometer, Tonopen, and Icare in patients with Keratoconus.

Methods: This cross-sectional study included 46 eyes of 26 patients with keratoconus. Intraocular pressure (IOP) is measured using easyton, icare, tonopen, and GAT. Measurements were compared and the influences of corneal topographic variables on IOP measurement were evaluated. Bland–Altman plots were used for assessing agreement between different tonometers.

Results: The mean age of the participants was 24.08±6.76 (range, 18–47) years (15 males and 11 females). The highest of the mean IOP values measured with different tonometers was obtained with Easyton (12.33±1.65), followed by Tonopen (11.59±2.17), GAT (10.67±1.52), and Icare (10.04±2.33). The mean IOP value measured with Easyton was significantly higher than that measured with GAT ($p<0.001$). There was no significant difference between GAT and either Tonopen ($p=0.154$) or Icare measurements ($p=0.732$). There was no significant difference between Tonopen and Easyton measurements ($p=0.421$). Icare measurements were correlated with central corneal thickness and keratometric values. GAT measurements were correlated with only Kmax. Thirty-eight (82.6%) of the differences were within the agreement limits (assumed clinically important deviation of up to ±2 mmHg) of GAT and Tonopen, 73.9% (n=34) were within the agreement limits of GAT and Icare, and 78.3% (n=36) were within the agreement limits of GAT and Easyton.

Conclusion: Compared with GAT, the gold standard method, Easyton IOP readings were higher, while both Tonopen and Icare readings were similar to GAT. All three tonometers showed acceptable agreement with the GAT, however, Tonopen showed the greatest agreement.

Keywords: Easyton transpalpebral tonometer, goldmann applanation tonometer, icare, intraocular pressure, keratoconus, tonopen

Introduction

Keratoconus is a bilateral, asymmetrical disease that results in progressive thinning and steepening of the cornea, causing irregular astigmatism and decreased visual acuity (1). Measurement of Intraocular pressure (IOP) in these patients is difficult due to the changes in the cornea affected by Keratoconus (2-5). It has been shown that tonometers such as Tonopen, Icare, dynamic contour tonometer, and ocular response analyzer, including the Goldmann applanation tonometry (GAT), which is accepted as the gold standard method for IOP measurement, are affected

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by the geometric (e.g., central corneal thickness [CCT], corneal curvature) and biomechanical (e.g., elasticity and rigidity) properties of the cornea (2-6). Furthermore, conflicting results regarding the agreement between tonometers have been reported in comparisons with different tonometers (2-6).

Transpalpebral tonometry provides IOP measurements without touching the cornea or having direct eye contact. The Easyton tonometer is an updated version of the transpalpebral tonometer. IOP is measured by recording the frequency of forced vibrations of the eye membranes under the influence of the tonometer's vibrator rod. The rod is placed in the sclera area onto the eyelid and compresses it under its own weight. A single interconnected biomechanical "rod-eye" ligament is formed, the vibration frequency of which is determined by the actual IOP (7). Transpalpebral IOP measurement has been suggested as an alternative method to prevent the effect of corneal pathologies on IOP measurements (4,8).

There are various studies in the literature comparing different tonometers in patients with keratoconus, and there is no consensus on which tonometer is most accurate in keratoconic eyes (2-6). To the best of our knowledge, IOP measurements in patients with keratoconus have not yet been studied with this new transpalpebral tonometer. This study aimed to determine the agreement between IOP measurements obtained using GAT, which is the gold standard method, and Easyton, Icare, and Tonopen measurements in keratoconic corneas and to evaluate the effect of corneal parameters on IOP measurements with these tonometers.

Methods

The study was approved by the Local Ethics Committee (Approval number: 85, August 10, 2022) and this research was consistent with the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Study Design and Population

In this cross-sectional study, 46 eyes of 26 patients who were diagnosed as having keratoconus in the cornea clinic of a tertiary academic center were included in the study. The diagnosis of keratoconus was made by experienced corneal specialists based on the presence of decreased vision caused by progressive irregular astigmatism and characteristic clinical features: Munson's sign, abnormal retinoscopy reflex, and biomicroscopic signs such as corneal protrusion, stromal thinning, Fleischer ring, Vogt striae, and prominent corneal nerve fibers. Corneal imaging was performed using Sirius topography (CSO, Italy) to confirm the diagnosis. The exclusion criteria included glaucoma, inflammatory disease, scarring or deformity in the upper eyelid, scleral and/or conjunctival pathology in the area of the Easyton tonometer rod's action, corneal apical scarring, previous corneal hydrops, and active ocular surface disease, and previous corneal crosslinking.

Contact lens wearers were instructed to stop using contact lenses 1 week before measurements. A complete ophthalmic examination was performed on all participants, including autorefractive measurements, best-corrected visual acuity, slit-lamp biomicroscopy, and fundus evaluations. All examinations and topographic imaging were performed before the IOP measurements.

IOP Measurements

IOP measurements were performed between 09:00 AM and 11:00 AM. Applanation methods were performed finally. Measurements were performed with Icare (IC200, Finland Oy, Helsinki, Finland), Tonopen (TPA; Reichert Inc., Depew, New York, USA), GAT, and Easyton (JSC Yelatma Instrument Making Enterprise, Russia), respectively. All measurements were taken in the sitting position. There were 15 min between the measurements taken with the different tonometers. Three consecutive measurements were obtained for each tonometer and average results were used for analysis.

The ICare tonometer is a rebound tonometer. The tonometer works by bouncing the probe off the cornea and measuring the deceleration of the probe to calculate the IOP value (9). The tip of the ICare disposable probe is positioned (approximately 5 mm) 4–8 mm from the center of the cornea along the central corneal axis. Tonometry performs six measurements for each set (automatic six-measurement mode [IC200-continuous]). The mean IOP is displayed after six consecutive measurements.

The Tonopen measures IOP over a small area of the cornea with a transducer tip using the principles of the Mackay-Marg.[10] All TonoPen measurements were made using a latex (Ocu-Film) cover over the tip. While holding the Tonopen unit perpendicular to the patient's cornea, the tip is gently touched on the cornea several times until a reading is displayed. After five valid readings are obtained, the averaged measurement will appear.

GAT measures IOP by measuring the spring force necessary to applanate a certain area of the cornea (Imbert-Fick law) (11). For GAT measurements, a drop containing topical anesthetic and fluorescein was applied to the patients. GAT measurements were performed using a slit-lamp under a cobalt blue filtered light after the tonometer scale was placed at 10 mmHg. The IOP was recorded in the steepest and the flattest meridian and the mean result was recorded.

When measuring with Easyton, the physician was positioned behind the patient. Patients were instructed to tilt their heads back and fix their gaze on an object at an angle of 45° to the horizontal axis. The physician stretched the upper eyelid with a finger of their free hand so that the upper eyelid margin and the limbus were aligned. The tonometer rod was placed on the patient's upper eyelid, 2–3 mm from its edge, holding the tonometer body vertically. For the device to ac-

curately determine the IOP, it must be held perpendicular to the globe. If the limbus is not positioned correctly, the measuring rod strikes the globe at an oblique angle and this may falsely lower the IOP measurements. The contact area of the tonometer is the upper eyelid that overlies the sclera, which corresponds to the corona ciliaris in the 12 o'clock meridian. One or 2 s after the tonometer tip touches the eyelid, the measured IOP value is displayed in its window.

Statistical Analysis

For statistical analyses, the Statistical Package for the Social Sciences (SPSS) Windows version 25.0 software (SPSS for Windows Inc., Chicago, USA) was used. The suitability of the quantitative data for normal distribution was tested using the Shapiro–Wilk test. The independent sample t-test or the Mann–Whitney U test was used to compare two groups depending on the distribution of variables. Repeated measures analysis of variance with Bonferroni correction was used to compare differences between IOP measurements obtained by different tonometers. Pearson's or Spearman's correlation analysis was used for the correlation analysis of IOP measurement techniques with each other and with corneal parameters. Bland–Altman analysis was performed to evaluate the agreement between the IOP measurements obtained with different tonometers (12). Statistical significance was accepted as $p<0.05$.

Table 1. Topographic findings of the participants

	Mean±SD (min-max)
Spherical refractive error, Diopters	-3.10±2.88 (-12.75–2.00)
Cylindrical refractive error, Diopters	-3.68±2.47 (-9.50–0.25)
K1	46.35±3.94 (40.42–59.25)
K2	49.20±4.48 (41.36–64.60)
Kavg	48.16±4.53 (40.88–61.81)
Kmax	56.25±7.56 (45.80–85.03)
CCT	466.95±46.87 (348.00–550.00)
Min CT	450.54±47.07 (319.0–537.00)

Kavg: Average keratometry; K_{max}: Maximum keratometry; CCT: Central corneal thickness; Min CT: Minimum corneal thickness; SD: Standard deviation.

Results

Forty-six eyes of 26 patients with keratoconus were enrolled in the study (15 males and 11 females). The mean age of the participants was 24.08±6.76 (range, 18–47) years. The topographic findings of the participants are shown in Table 1.

The highest of the mean IOP values measured with the different tonometers was obtained with Easyton, followed by Tonopen, GAT, and Icare. The mean IOP values measured with Easyton were significantly higher than that measured with GAT ($p<0.001$). There was no significant difference between GAT and either Tonopen ($p=0.154$) or Icare measurements ($p=0.732$). There was no significant difference between Tonopen and Easyton measurements ($p=0.421$). The results of IOP measurements taken with different tonometers are shown in Table 2.

Correlation analyses between the IOPs measured using different tonometers are shown in Table 3. GAT measurements were moderately correlated with all other tonometers.

Correlation analyses between the IOPs measured using different tonometers and the corneal topographic parameters are shown in Table 4. Icare measurements were correlated with CCT and keratometric values. GAT measurements were correlated with only Kmax.

The Bland–Altman plots of the agreement between GAT and Tonopen, Icare, and Easyton are represented in Figures 1-3. The limits of agreement for GAT and Tonopen (±0.96 SD) were −5.35 and 3.52 mmHg, for GAT and Icare they were −3.0 and 4.27 mmHg, and for GAT and Easyton, they were −4.83 and 1.53 mmHg, respectively. Thirty-eight (82.6%) of the differences were within the agreement limits (assumed clinically important deviation of up to ±2 mmHg) of GAT and Tonopen, 73.9% (n=34) were within the agreement limits of GAT and Icare, and 78.3% (n=36) were within the agreement limits of GAT and Easyton.

Table 2. Comparison of intraocular pressure measurements obtained with different tonometers

		p			
	IOP, mmHg Mean±SD (range)	Difference from GAT	Difference from Easyton	Difference from Tonopen	Difference from Icare
GAT	10.67±1.52 (8.0–14.0)		<0.001	0.154	0.732
Easyton	12.33±1.65 (8.0–15.0)	<0.001		0.421	<0.001
Tonopen	11.59±2.17 (8.9–16.95)	0.154	0.421		0.001
Icare	10.04±2.33 (7.10–15.70)	0.732	<0.001	0.001	

IOP: Intraocular pressure GAT: Goldmann applanation tonometer, SD: Standard deviation, (ANOVA) with Bonferroni.

Table 3. Correlation analyses between the IOPs measured using different tonometers

	GAT		Easyton		Tonopen		Icare	
	r	p	r	p	r	p	r	p
GAT			0.422*	0.004	0.387*	0.008	0.606*	0.000
Easyton	0.422*	0.004			0.016	0.915	0.260	0.081
Tonopen	0.387*	0.008	0.016	0.915			0.207	0.167
Icare	0.606*	0.000	0.260	0.081	0.207	0.167		

IOP: Intraocular pressure; GAT: Goldmann applanation tonometer.

Table 4. Correlation analyses between the IOPs measured using different tonometers and the corneal topographic parameters

	GAT		Tonopen		Icare		Easyton	
	r	p	r	p	r	p	r	p
K1	-0.076	0.615	0.047	0.757	-0.387*	0.008	-0.122	0.421
K2	-0.289	0.052	-0.031	0.836	-0.494**	0.000	-0.152	0.312
Kavg	-0.256	0.107	0.009	0.958	-0.379*	0.015	-0.286	0.070
Kmax	-0.362*	0.013	-0.046	0.762	-0.612**	0.000	-0.281	0.059
CCT	0.108	0.508	-0.259	0.107	0.358*	0.015	0.301	0.059
MinCT	0.131	0.385	-0.274	0.066	0.309	0.053	0.216	0.149

Kavg: Average keratometry, Kmax: Maximum keratometry, CCT: Central corneal thickness, Min CT minimum corneal thickness.

Discussion

Goldmann applanation tonometer is the most widely used tonometry for IOP measurements due to its low intraobserver and interobserver variability and ease of use and is considered the gold standard. However, it is affected by various corneal parameters (2-6). Therefore, the search for new tonometry continues for accurate IOP measurements in corneal pathologies. Keratoconus is one of the diseases in which IOP measurement is difficult. The GAT tends to underestimate IOP in keratoconic eyes due to reduced corneal thickness and increased corneal curvature (3). It has also been shown that GAT is significantly affected by corneal hysteresis and corneal resistance factor. In keratoconus patients, the increase in CH and the decrease in CRF were associated with a lower GAT measurement (2,4). There is no consensus in the literature about tonometry as to which method provides the most accurate IOP measurements in patients with keratoconus (2-6).

Transpalpebral tonometry bypassing the cornea has come to the fore in corneal pathologies as an effective alternative to GAT. Previous transpalpebral tonometer versions were compared with GAT and although some studies reported acceptable agreement, (8,13) others reported poor agreement with GAT and it is not recommended to be used instead of GAT in the diagnosis and follow-up of glaucoma in clinical practice (14-16). Toker et al., in their study in which healthy subjects were divided into groups according to CCT, emphasized that Diaton tonometry was affected by corneal thickness in thinner corneas and estimated IOP lower than GAT (8).

In the first study to examine transpalpebral tonometry in patients with keratoconus, the authors found GAT and Diaton measurements to be similar and reported a low but significant correlation between the two tonometer measurements (5). However, although the mean difference in IOP measurement was extremely small, a large measurement variation was reported. Only 16% of the measurements were within the 2 mmHg compliance range. In our study, the mean IOP value measured using Easyton was higher than that measured with GAT. Although the difference between the two tonometer readings was significant, 78.3% of the measurements were within the 2 mmHg compliance range. In addition, a moderately significant correlation was found between GAT and Easyton measurements. Studies comparing keratoconus patients with healthy controls have shown that eyes with keratoconus exhibit low IOP values (2). In these patients, the geometric and biomechanical alternations of the cornea were associated with the underestimated IOP

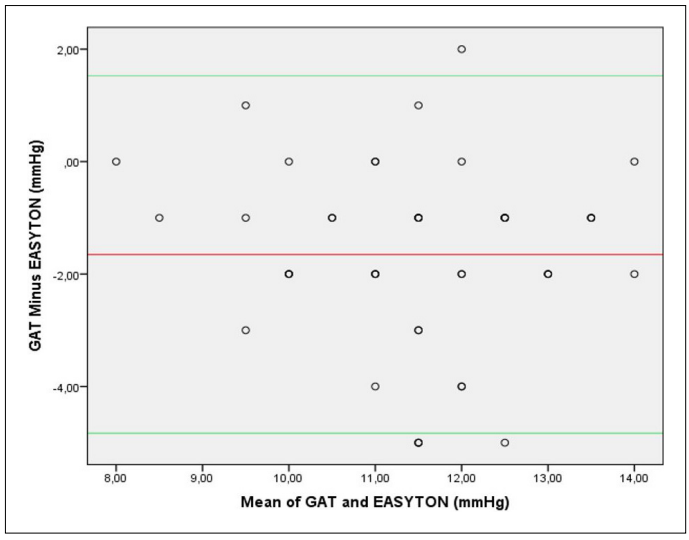

Figure 1. Bland-Altman plot comparing between Goldman applanation tonometry and Easyton. The middle horizontal line indicates the mean difference; the upper and lower horizontal lines indicate 95% agreement limits (mean difference ±1.96SD).

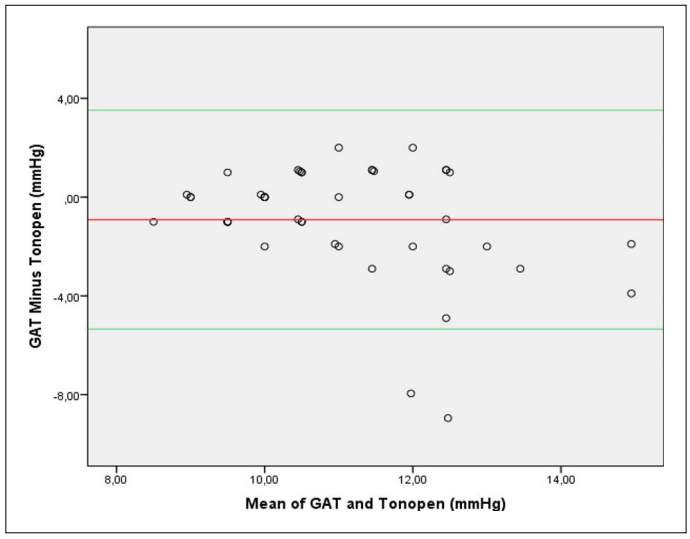

Figure 2. Bland-Altman plot comparing between Goldman applanation tonometry and Tonopen. The middle horizontal line indicates the mean difference; the upper and lower horizontal lines indicate 95% agreement limits (mean difference ±1.96SD).

(2-4). Therefore, the IOP measurement by Easyton, which is unaffected by corneal features, may reflect closer reading to the actual IOP in these eyes. In keratoconus, which is a progressive disease, corneal parameters change over time. In addition, surgical procedures such as intrastromal corneal ring segments implantation and crosslinking change the corneal morphology. Considering these, transpalpebral tonometry may be useful in the screening and follow-up of patients with Keratoconus.

Tonopen is based on the principle of applanation, but the applanation area is smaller than in GAT, so it is recommended

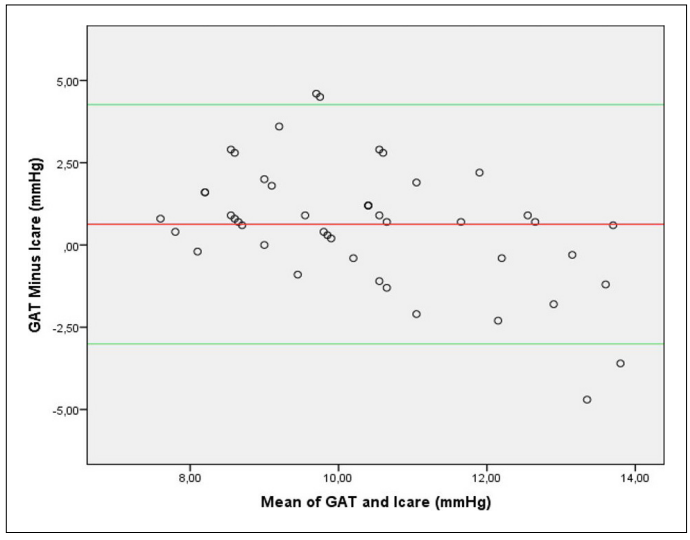

Figure 3. Bland-Altman plot comparing between Goldman applanation tonometry and Icare. The middle horizontal line indicates the mean difference; the upper and lower horizontal lines indicate 95% agreement limits (mean difference ±1.96SD).

for pathologic corneas. In the study of Bilgeç et al., GAT and Tonopen measurements were similar in keratoconic eyes and Tonopen was the least affected tonometer by corneal parameters (2). Altınkaynak et al. found no statistically significant relationship between Tonopen measurements and CCT in eyes with keratoconus but reported that there were statistically significant differences in IOP in eyes with keratoconus when compared with the control group and between keratoconus stages. Based on these results, they did not recommend Tonopen as an appropriate tonometer for patients with keratoconus (6). In our study, the most compatible IOP measurements with GAT were obtained with Tonopen; 82.6% of the measurements were within the 2 mmHg compliance range. In addition, there was no relationship between corneal parameters and Tonopen measurements.

Icare is another tonometer recommended for pathologic corneas. In previous studies comparing Icare and other tonometers, conflicting results were reported in both healthy subjects (17-20) and patients with keratoconus (2,3,21). Bilgeç et al. reported that IOP measurements obtained with Icare in patients with keratoconus were higher than Tonopen and GAT measurements (2). By contrast, Özcura et al. reported that Icare underestimated IOP according to GAT measurements in keratoconic corneas (3). Mendez-Hernandez et al. observed the greatest agreement with GAT for ICare in IOP measurements taken with Tonopen, Pascal dynamic contour tonometry, Icare, ocular response analyzer, and GAT in eyes with keratoconus (20). Reported results regarding the effect of corneal parameters on Icare measurement are also contradictory (19,22,23). In eyes with keratoconus, correlations have been shown be-

tween IOP measurements and corneal geometric (corneal thickness and corneal radius of curvature) (3,21) and biomechanical parameters (corneal resistance factor and corneal hysteresis) (2). In our study, Icare and GAT measurements were similar and acceptable agreement was shown between two tonometers. However, there was a significant correlation between Icare measurements and CCT and keratometric values. These results confirm that Icare can be affected by corneal parameters and makes the use of Icare in patients with keratoconus controversial.

The current study had several limitations. One of these limitations was the relatively small sample size. The second is corneal biomechanical properties could not be evaluated. Furthermore, with Icare and Tonopen, measurements are only obtained from the central cornea and are unlikely to align with the cone location or thinnest corneal point in keratoconus, which should be taken into account when investigating the relationship between IOP measurements and corneal parameters. In patients with Keratoconus, IOP measurement can be evaluated through multiple measurements taken from different corneal quadrants.

Conclusion

In our study, Tonopen showed the greatest agreement with GAT, which is accepted as the reference method, in IOP measurements taken using Icare, Tonopen, GAT, and Easyton in eyes with Keratoconus. Icare shows acceptable agreement with the GAT; however, it seemed to be affected by corneal parameters. Although Easyton readings were statistically higher than GAT readings, an acceptable agreement was shown with the GAT measurements in the majority of cases. Therefore, it should be kept in mind as an alternative in pathologic corneas. To evaluate the most accurate tonometry method in kertoconic eyes, further studies are needed in larger patient groups.

Disclosures

Ethics Committee Approval: The study was approved by the Local Ethics Committee (Approval number: 85, August 10, 2022) and this research was consistent with the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants.
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