ORIGINAL ARTICLE

Comparison of Goldmann applanation, non-contact, dynamic contour and tonopen tonometry measurements in healthy and glaucomatous eyes, and effect of central corneal thickness on the measurement results

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ABSTRACT

Aim To compare the correlation of intraocular pressure (IOP) measurements obtained using Goldmann applanation tonometry (GAT), non-contact tonometry (NCT), dynamic contour tonometer (DCT) and tono-pen (TP) in glaucomatous and healthy eyes, and to investigate the effect of central corneal thickness (CCT) on the measurements.

Methods One hundred eyes of 100 glaucoma patients and 50 eyes of 50 healthy individuals were compared. In all of the eyes, CCT was evaluated using ultrasonic pachymeter. IOP was measured using NCT, TP, DCT and GAT, respectively. IOP measurements and correlation of these measurements with CCT were calculated using Pearson and intra-group correlation analysis.

Results In the glaucoma group, the mean IOP was 16.42 ± 2.80 mmHg with NCT, 17.12 ± 2.49 mmHg with TP, 18.27 ± 2.62 mmHg with DCT and 16.08 ± 3.00 mmHg with GAT. The mean CCT was 532.15 ± 39.08 μm. In normal individuals, mean IOP was 14.64 ± 2.20 mmHg with NCT, 15.32 ± 1.85 mmHg with TP, 16.72 ± 2.31 mmHg with DCT and 14.16 ± 2.80 mmHg with GAT. The mean CCT was 538.40 ± 31.64 μm.

Conclusion A strong compliance between NCT and GAT has been observed. NCT can be used instead of GAT.

Keywords: intraocular pressure, glaucoma, cornea, tonometer, pachymeter

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INTRODUCTION

Glaucoma is a chronic, progressive, multifactorial optic neuropathy, which is characterized by ganglion cell loss, cupping of the optic disc and visual field defects (1). Intraocular pressure (IOP) value is one of the most important parameters in the diagnosis, classification, follow-up and treatment of glaucoma and ocular hypertension. Currently, decreasing the IOP is a-valid treatment option in preventing the progression of glaucomatous damage (2). For this reason, determining the true IOP value is very important in glaucoma treatment. The IOP measurements vary depending on many factors, such as the different methods in calibration of the instruments, individual factors, i.e. current systemic blood pressure, heart rate, respiratory rhythm, positional status and the current systemic blood pressure, heart rate, respiratory rhythm, body position of the person measured by the IOP (2). Corneal thickness and corneal curvature are also the local factors that affect the measurements (2).

Today, Goldmann applanation tonometry (GAT) is widely used, highly accepted and considered as the gold standard among the IOP measurement methods (3-5). However, being attached to the biomicroscope, the difficulties in positioning it properly for some of the patients, difficulties of cooperation in children, returning erroneous results in irregular astigmatism and oedematous corneal cases with scars, causing corneal abrasions, requiring training for being able to do measurements, and causing inter-eye contamination are the major disadvantages of GAT (6-8). Tonopen (TP) hand tonometry, non-contact tonometer (NCT) and dynamic contour tonometer (DCT) are devices that are designed to overcome these disadvantages. It has been shown in various publications that tonometer is affected at varying rates by central corneal thickness (CCT), even if all these drawbacks are eliminated (6,7).

In this study, we aimed to determine the correlation between GAT, TT, NCT and DCT and IOP measurement results in glaucoma patients and healthy individuals followed in our clinic and to identify the correlation of these measurements with CCT. In addition, we wanted to investigate the best alternative tonometry device to the GAT, especially for screening programmes.

PATIENTS AND METHODS

Patients and study design

One hundred eyes of 100 patients (Group 1), who were diagnosed with glaucoma in the Glaucoma Unit of the Department of Ophthalmology in Yuzuncu Yil University, Turkey, and 50 eyes of 50 healthy individuals (Group 2) were included in the study. The groups were age-matched. The right eyes of all of the patients were included in the study. Before proceeding, the procedure was clearly explained to all subjects and a signed and informed consent form was obtained. Permission for the study was obtained from the Ethics Committee of Yuzuncu Yil University, Turkey. During the study, all the ethical principles and basic principles defined for biomedical research in the Helsinki Declaration were followed.

Glaucoma patients included in the study (Group 1) were diagnosed according to IOP level, gonioscopic examination, optic nerve head appearance and consecutive visual field examination. The control group (Group 2) was composed of healthy consecutive individuals with no glaucoma anamnesis and normal ocular examination, who applied to the outpatient clinic for refractive examination.

Exclusion criteria were: patients with ocular surface disease (corneal oedema, scarring, dystrophy, etc.), those who were hyperopic or myopic over ± 3 dioptres, and patients who had astigmatic diopter over ± 1, irregular astigmatism, patients with dry eye, those who used contact lenses, patients who had recent previous glaucoma crisis due to the possible corneal oedema, those with serious eye diseases such as proliferative diabetic retinopathy with iris neovascularization, uveitis, patients with previous ocular surgery (including refractive surgery) and patients with ocular trauma, pregnant women, those with a GAT and IOP of 25 mm Hg or above and a quality score of 4 or 5 measured by DCT.

Methods

All four methods, GAT, TP, NCT and DCT, including the pachymeter, were explained to the patients in advance, e. g. that the application would be painless, allowing the IOP to be measured and prevented from closing and distressing the eyelids. The patients were asked not to rub their eyes, to wipe them or to put pressure on their eyelids with their hands after the application. All

of the IOP measurements were made at the sitting position due to the fitting of the most of the tonometers to the constructed biomicroscopes. We did not investigate the difference between sitting and upright positions.

All eyes were first subjected to CCT measurement with an ultrasonic pachymeter (Nidek US-1800 Echoscan, Japan). Then, measurements were made with non-contact tonometry (Keeler the pulsair eye, USA), tonopen (Tono-Pen XL, Medtronic Solan, USA), dynamic contour tonometry (SMT Swiss Microtechnology, Switzerland) and Goldmann applanation tonometer, respectively. In all the measurements the arithmetic average of the 3 measurement values were taken. For repeated IOP measurements, they were made with a 15-minute pause, which is regarded as the safe interval (9). All the measurements were made by the same ophthalmologist, who is an experienced specialist. The measurements were made at around the same time of day, around 10 o'clock before lunch. While calculating the CCT, before the measurement, 0.5% topical proparacaine hydrochloride (Alcaine, Alcon) was dropped to the eye to provide topical anaesthesia. Thereafter, measurements were made using ultrasonic pachymeter on the midpupillary axis, placing the pachymetry probe perpendicular to the cornea without applying pressure on the cornea. In the IOP measurements made with NCT, no topical anaesthetic drops were used and the patient was asked to be fixated to the green light of the tonometry. Measurement of IOP with GAT was performed under cobalt blue light after topically anaesthetizing the patient, using fluorescein sodium impregnated sterile strips. During this time, all patients were asked to look behind the doctor with their eyes open and to breathe freely. With a TT that was recalibrated every day, a separate sterile disposable cap was used for IOP measurement on each eye. Prior to the measurement, topical anaesthesia was applied, and later, the procedure was performed while the patient was looking across. On the liquid crystal panel, averages of measurements with reliability ≤ 10% were taken. The IOP measurements were also made with DCT under topical anaesthesia. When the patient was in the position of looking across, the endpoint of the tonometry was contacted to the cornea and the centralization was checked on the biomicroscope. It touched the cornea for approximately 5-6 seconds. On the screen, the measurements with reliability values of 1st, 2nd and 3rd quality level were taken into account and their averages were taken into consideration.

Statistical analysis

In the statistical analysis of the obtained data, one-way analysis of variance (One-way ANOVA) was performed to determine whether there was a difference between the patient and control groups in terms of the studied characteristics. In the groups, the Pearson correlation coefficient was calculated in determining the relationship between the properties. In addition, the intra-group correlation coefficient was calculated to determine the compatibility between the GAT method and other methods. In the calculations, the levels of 5% and 1% were accepted as significant ($p<0.01$ and $p<0.05$). In terms of the studied characteristics, descriptive statistics were expressed as mean and standard deviation.

RESULTS

The mean age was 54.70 ± 11.69 years (32-82 years) for glaucomatous patients and 51.46 ± 9.04 years (31-72 years) for healthy individuals.

The mean CCT value was 532.15 ± 39.08 μm (447-651 μm) in patients with glaucoma and 538.40 ± 31.64 μm (480-619 μm) in healthy individuals. The IOP averages measured with all instruments were presented in Table 1. Measurements with DCT were highest in both patient and control group, lowest with GAT. The difference between the mean of the patient and control groups was significant except for CCT ($p<0.01$)) (Table 1).

Table 1. Gender, age, central corneal thickness (CCT) and intraocular pressure (IOP) values measured by tonometer in patient and control groups

Variable	Mean±SD (range)		p
	Patients with glaucoma (n=100)	Patients with normal eye (n=50)	
Age (years)	54.70 ± 11.69 (32-82)	51.46 ± 9.04 (31-72)	0.10
CCT (μm)	532.15 ± 39.08 (447-651)	538.40 ± 31.64 (480-619)	0.32
GAT (mmHg)	16.08 ± 3.00 (10-24)	14.16 ± 2.80 (10-22)	0.00
NCT (mmHg)	16.42 ± 2.80 (10-24)	14.64 ± 2.20 (10-19)	0.00
TP (mmHg)	17.12 ± 2.49 (10-27)	15.32 ± 1.85 (11-20)	0.00
DCT (mmHg)	18.27 ± 2.62 (12-30)	16.72±2.31 (11.5-23)	0.00

GAT, Goldmann applanation tonometry; NCT, non-contact tonometer; TP, Tonopen; DCT, dynamic contour tonometry

When the differences between IOP measurement methods between patient and control groups were examined, the highest IOP measurement difference was observed between DCT and GAT. The difference was 2.19 ± 2.24 mmHg in the patient group and 2.56 ± 1.94 mmHg in the control group. The lowest difference was observed between NCT and GAT measurements. The difference was 0.34 ± 1.13 mmHg in the patient group and 0.48 ± 1.16 mmHg in the control group. In both groups, the differences between the measurements of the devices were statistically significant (p<0.01) (Table 2).

Table 2. Differences in intraocular pressure (IOP) measurement methods between patient and control group

Variable	Mean difference±SD		p
	Patients with glaucoma (n=100)	Patients with normal eye (n=50)	
DCT – NCT	1.85 ±1.88	2.08 ± 1.43	0.00
DCT- GAT	2.19 ±2.24	2.56 ± 1.94	0.00
DCT- TP	1.15 ±0.75	1.40 ± 1.09	0.00
NCT- GAT	0.34 ±1.13	0.48 ± 1.16	0.00
TP - NCT	0.70 ±1.63	0.68 ± 1.39	0.00
TP - GAT	1.04 ±1.97	1.16 ± 2.05	0.00

GAT, Goldmann applanation tonometry; NCT, non-contact tonometer; TP, Tonopen; DCT, dynamic contour tonometry

When GAT was accepted as the gold standard for accurate measurement of IOP, the compliance with GAT for other measurement methods in the patient and control groups was presented in Table 3. According to intra-group correlation coefficients (ric), the most compatible tonometry measurements with GAT were NCT in both groups and the most incompatible tonometry measurements were with DCT in patient and with TP in control group (p<0.01)

Table 3. Measurements in the glaucoma patient group and Pearson correlation coefficients between each tonometer and central corneal thickness (CCT)

Variable	Pearson correlation coefficient (rp)				
	DCT	NCT	GAT	TP	CCT
DCT	1				
NCT	0.760*	1			
GAT	0.690*	0.927*	1		
TP	0.958*	0.816*	0.748*	1	
CCT	-0.033	0.446*	0.533*	0.009	1

*p<0.01
GAT, Goldmann applanation tonometry; NCT, non-contact tonometer; TP, tonopen; DCT, dynamic contour tonometry

When the correlation between IOP measurements and CCT in the patient and control groups was analysed by Pearson's correlation coefficient (Tables 3 and 4), IOP measurements were only correlated with GAT, NCT and CCT in both groups, that is, it was affected by CCT. DCT and TP were not affected by CCT in both groups. In the patient group, Pearson's correlation coefficient (rp) between GAT and CCT was 0.533 and rp value between NCT and CCT was 0.464. In the control group, the rp value between GAT and CCT was 0.471, and the rp value between NCT and CCT was 0.369 (p<0.01). According to these values, GAT had the highest correlation with CCT in both groups. Additionally, it was determined that DCT and TP did not correlate with CCT (p>0.05).

Table 4. Measurements in the control group and Pearson correlation coefficients between each tonometer and central corneal thickness (CCT)

Variable	Pearson correlation coefficient (rp)				
	DCT	NCT	GAT	TP	CCT
DCT	1				
NCT	0.800*	1			
GAT	0.729*	0.920*	1		
TP	0.886*	0.778*	0.683*	1	
CCT	0.036	0.369*	0.471*	0.009	1

*p <0.01
GAT, Goldmann applanation tonometry; NCT, non-contact tonometer; TP, Tonopen; DCT, dynamic contour tonometry

DISCUSSION

It has previously been demonstrated that the IOP measurements made with GAT are influenced by CCT. The CCT is an important factor affecting the end results in tonometry operated with applanation principle. Corneal flattening is achieved by applying less force in thin corneas while using more power for applanation in CCT thick eyes. For this reason, IOP can be measured above normal in cases with high CCT and erratically low in thin corneas (8, 10-12).

It has also been shown in many studies that NCT is affected by CCT, in a way similar to GAT (13-14). Siganos et al. found significant correlations between CCT and GAT and NCT measurements and found 0.3 mmHg IOP increase for 10 μm CCT. Tonnu et al. found that all methods were influenced by CCT, but that this effect was at its highest level for NCT, in their studies comparing GAT, TP, NCT tonometer methods (12). Another study compared NCT and GAT in 230 eyes of 115 patients, NCT was reported to be more affected than CCT according to GAT. In the same study, it was reported that the measurements were low in the thin corneas and high in the thick corneas, and especially there were errors in corneal oedema (15). We also found that GAT and NCT were affected by CCT in the patient and control groups. We observed that this effect was

also greater in the GAT in both groups.

It is claimed that DCT makes IOP measurements independently of the structural features of the cornea. Ku et al. reported that in patients with healthy corneas, IOP values correlated strongly with CCT and GAT and that the correlation between IOP values obtained with DCT and CCT was on the significance limit (16). There are a number of studies indicating that DCT was not affected by CCT (10, 17-21). Viestenz et al. and Salvetat et al. reported that measurements were affected by CCT (22,23). We also showed that DCT was not affected by CCT in our study. In many studies, TP was also found to be affected by CCT, but less affected by GAT and NCT (11,12,14,23). Two studies have shown that TP is not affected by CCT (22,24). This result indicates that Tonopen is less affected than CCT by smoothing a smaller area of contact (1.5 mm for Tonopen XL) in comparison to GAT. In our study, it was shown that Tonopen was not affected by CCT.

When we looked at the compliance between the tonometers in our study, the most compatible TTM with GAT was NCT. The difference was 0.34 ± 1.13 in the glaucoma group and 0.48 ± 1.16 mmHg in the patient group. The compliance coefficient was 0.927 in the glaucoma group and 0.920 in the normal group. The lowest compliance with GAT was detected in DCT. DCT was measured by GAT in our study of 2.19 ± 2.24 mmHg in the patient group and 2.56 ± 1.94 mmHg in the control group. This has already been shown in some studies (20,21). In a study by Broman et al comparing DCT and GAT in 100 eyes with glaucoma, DCT was measured approximately 1.8 mm Hg higher than GAT. However, it was observed that both devices were compatible with each other (20). Our study showed excellent agreement between DCT and TP (0.9 in both patient and glaucoma group), although there was an agreement between DCT and GAT. TP can be used as an alternative to irregular, scarred and oedematous corneas. It is a hand tonometer which is easy to use, does not need biomicroscope and can measure quickly, especially reducing the disadvantages of GAT. In many studies, TP and GAT compliance has been demonstrated in individuals with normal IOP (8,13,24). We have found a moderate agreement between GAT and TP in our study. However, we found that the compatibility of the TP with the other two tonometers was greater than that of the GAT (highest compliance with DCT).

One of the disadvantages of our study is lack of a group that 2 modified corneal thickness by the effect of excimer laser. We cannot show the best way of measuring intraocular pressure in these patients.

In conclusion, the ability to measure IOP independently of corneal thickness is important in the definition of glaucomatous disease in eyes undergoing refractive corneal surgery, in cases where CCT cannot be measured, or in conditions that cause thinning and thickening of corneal. Hence, tonometers that are not affected by CCT come to the forefront in IOP measurements in these cases. In our study, it was observed that the compliance between DCT and TP was well, and both devices were unaffected by CCT. A strong compliance between NCT and GAT has been observed, and it can be said that NCT can be used instead of GAT. Both tonometers were shown to be affected by CCT in our study.

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TRANSPARENCY DECLARATION

Conflicts of interest: None to declare.

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