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Original Article

Measurement of Intraocular Pressure with Applanation, Dynamic Contour, and Air-Puff Tonometers: A Comparative Study in Primary Open-Angle Glaucoma and Healthy Cases

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Abstract

Objectives: This study aimed to investigate and compare the reliability of Goldmann applanation tonometer (GAT), dynamic contour (DCT), and noncontact (NCT) tonometers in intraocular pressure (IOP) measurement and the affecting parameters in healthy subjects and cases with primary open-angle glaucoma (POAG).

Methods: Left eyes of 64 cases (32 males and 32 females) were selected for this prospective, controlled study. Of these cases, 33 had POAG, and 31 were selected as control. IOP measurement was performed using NCT, DCT, and GAT consecutively for each patient, and then central corneal thickness (CCT) was measured. Ocular pulse amplitude (OPA) and all values were recorded.

Results: The mean age was 53.36±10 years (31–80 years), and CCT was 561±45 µ. IOP was found as 16.39±3.75 mmHg with GAT, 17.89±3.55 mmHg with DCT, and 15.76±3.49 mmHg with NCT. A significant difference was found between DCT with NCT and GAT. Whereas, a positive correlation was found between CCT with all the three methods used, with DCT as the weakest. While the correlation between all the three methods was excellent, the strongest was found to be between DCT and GAT. Thick corneas affected all the three methods, but DCT was the least affected. While DCT tends to measure higher than both GAT and NCT, this difference decreased as the corneal thickness increased. OPA was found to be 2.56±1.04 mmHg; no statistical difference was found between the groups. A correlation was found between OPA and IOP, and OPA was found to be significantly higher in women.

Conclusion: DCT is minimally affected by corneal factors, especially in thin corneas, and shows excellent correlation with GAT. This new-generation digital tonometer can be used safely in glaucoma diagnosis and follow-up.

Keywords: Intraocular Pressure, Ocular, Open-Angle Glaucoma, Ocular Pulse Amplitude, Pascal Dynamic Contour tonometer, Tonometry.

Introduction

Glaucoma is a group of diseases that develop due to several factors including an imbalance in the production and outflow of aqueous humor, changes in ocular blood flow, and factors affecting ganglion cell apoptosis. Glaucoma presents itself with progressive atrophy in the optic nerve head and loss of visual field as a result of the loss of the nerve fibers and ganglion cells and progresses to blindness if left untreated (1,2). The relationship between blindness and high ıntraocular pressure (IOP) was mentioned for the first time in medieval Arabic sources (3).

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Previous literatures showed that an average of 3% (0.5%–6.6%) of the general population is affected by glaucoma, and this rate increases with advancing age, but half of the patients are not aware of this situation, and most of them are not treated (2,4-6).

Primary open-angle glaucoma (POAG) is a disease with a course of high IOP, distinctive papillary cupping, and visual field loss. Initial findings are vague, often asymptomatic, progressive, and bilateral anterior optic neuropathy.

Lowering the IOP is the basis of glaucoma treatment. IOP is the most important and the only modifiable risk factor at present (3,7). After the fourth decade, IOP is found below 21 mmHg in 90%–95% of the healthy population. The disease progresses as IOP increases, suggesting that high IOP may be the most critical factor in glaucoma (3,8,9).

Several tonometers are used in IOP measurement. The method used for measuring the IOP came to the agenda after 1885, and devices with different technical features were developed. Tonometers are devices that use the physical principles adapted to the mechanical properties of the eye (10,11).

The Goldmann applanation tonometer (GAT) was defined in 1956 and is still considered as the gold standard of IOP measurement today. Pneumatic noncontact tonometers (NCT), which came into use in 1972, have taken their place in ophthalmology practice thanks to its ease of use (10-13). Dynamic contour tonometer (DCT), besides IOP measurement, can also measure ocular pulse amplitude (OPA) (13,14). IOP, which pulsates with the cardiac cycle, does not actually have a fixed value. Ninety percent of the blood coming to the ophthalmic artery during systole passes into the choroidal blood flow. OPA is the difference between systolic and diastolic IOPs. OPA is likely to be an indirect indicator of choroidal blood flow clinically (13-15). DCT is a widely used tonometer that is aimed to perform IOP measurement without being affected by the central corneal thickness (CCT), corneal rigidity, and keratometric parameters without performing a change in shape of the cornea during measurement. Kanngiesser (16) explained the theoretical background and measurement principles of DCT, which eliminates the errors caused by corneal factors in other tonometers using the principles of applanation and indentation. They stated that the sources of error in the measurement of IOP using DCT were minimized (15-17). DCT is a digital, third-generation tonometer designed for continuous IOP measurement with a sensitivity of 0.1 mmHg without being affected by corneal factors (16,17).

Our study aimed to investigate whether DCT is a tonometer as successful as claimed, whether it is superior to gold standard GAT, and whether it can make healthy measurements in both glaucoma and healthy cases during routine examination. The measurements between GAT, NCT, and Pascal DCT, reliability, advantages, and disadvantages of each technique were compared in detail using method comparison techniques and different corneal thickness groups between POAG cases and healthy controls. Particularly, a comparison of portable air-puff NCT (Pulsair IntelliPuffTM, Keleer Limited 2007, Berkshire, UK) versus DCT and GAT altogether in the literature has not been reported before as far as we know.

Methods

This study was conducted in Bezm-i Alem Valide Sultan Vakıf Gureba Training and Research Hospital according to the ethical principles contained in the Helsinki Declaration. A written informed consent was obtained from all patients and volunteers, and the approval of the local ethics committee was obtained for this prospective and controlled study. This study included 64 eyes of the 64 patients consisting of volunteer patients and healthy individuals between 2009 and 2010, including only the left eye of each individual. The patient group consisted of 33 patients with POAG who did not have progression with medical treatment, and the control group consisted of 31 individuals who were found to be healthy after a routine ophthalmological examination. Parameters including age, sex, and personal and family history for systemic and ocular diseases were recorded. Best-corrected visual acuity was measured, and anterior segment and fundus examination was made with slit-lamp during routine eye examination. Cases with any refractive errors higher than three diopters (D), corneal pathology, inflammatory eye and retinal diseases, trauma, or ocular surgery were excluded from the study. Retina, optic nerve head, and nerve fiber examination was done using +90D lens. Anterior chamber angle evaluation was performed using Goldmann three-mirror gonio lens, and only cases with an open angle were included in the study.

Humphrey (Humphrey Field Analyzer; Carl Zeiss Meditec, Dublin, CA, USA) was used for standard automated perimetry (SAP), and visual field analysis was performed using Stat-Pac statistics program. Glaucoma hemifield test (GHT, 30-2, full threshold), pattern standard deviation (PSD) data, and mean deviation (MD) were used. GHT "out of normal limits," "p<5%," and MD >3.5 dB for PSD were evaluated as significant visual field defects of glaucoma. In the healthy group, the condition was between MD <2 dB, and PSD was 95% within the normal range. Retinal nerve fiber layer (RNFL) thickness was measured by selecting the fast RNFL (3.4 mm) protocol of the optical coherence tomography (Zeiss Stratus®-3, software version5.0, Carl Zeiss Meditec, CA, USA). The shots in which the optical disk is not at the center, or the signal strength is below six, were not taken into consideration. The mean peripapillary RNFL measurements were found to be out of normal limits according to

the rapid protocol nomogram and were often below 90 microns in glaucoma cases. In healthy cases, the condition of being within normal limits and above 90 microns, according to nomogram, was sought.

CCT measurements were made using an ultrasonic pachymetry device (Nidek UP-1000; Nidek Technologies, Gamagori, Japan). An average of three consecutive measurements (standard deviation ±5 microns) in the eyes before pupillary dilation was taken for CCT. When comparing IOP measurements made with three different devices, the CCT <520 µ, those between 520 and 580 µ, and those with >580 µ were evaluated as "thin," "medium," and "thick" cornea, respectively.

In all cases, the IOP measurement was performed between 14 and 16 PM at the same time of the day, by the same clinician (KTÖ), with minimum 10-min intervals by NCT, then DCT, and lastly, GAT.

Three consecutive IOPs were measured using air-puff NCT (Pulsair IntelliPuff TM, Keleer Limited 2007, Berkshire, UK) at 5-min intervals, and their averages were recorded as IOP1 if the difference between them is not >3 mmHg.

DCT (Pascal tonometer, Swiss Microtechnology AG, Port, Switzerland), IOP, and ocular pulse amplitude (OPA) measurements were performed after instillation of topical 0.5% proparacaine hydrochloride (Alcaine®, Alcon, Texas, USA), and the measurement quality 1 and 2 were recorded as IOP2 and OPA. The ones with 3-4-5 measurement quality were repeated after 10 minutes, and the measurements which are not of the first or the second quality were not included in the study.

IOP measurement with GAT (Haag-Streit, Bern, Switzerland) was performed after corneal staining using fluorescein (fluorescein strips, Haag-Streit, Bern, Switzerland) following topical anesthesia.

All patients were evaluated in detail to exclude the possibility of ocular hypertension (OHT) or normotensive glaucoma (NTG).

Cases with increased optic disk cupping or an asymmetric cup-disk ratio (c/d), RNFL loss in red-free funduscopy, visual field defect compatible with glaucoma (PSD <5% and MD >3.5 dB), RNFL thickness below 90 microns and defective according to nomogram, open-angle on gonioscopy, and those without a secondary cause were considered as POAG.

Cases with normal optic disc appearance and a c/d ratio within normal limits, with normal RNFL thickness according to nomogram (mean >90 microns), and without visual field defect (PSD in the normal range and MD <2 dB) were considered healthy and were included in the control group.

MedCalc version 10.1 (MedCalc, Turkey) and SPSS version 16.0 (SPSS Inc., Chicago, IL, USA) were used to perform statistical analysis. Comparisons of the averages were made using the one-way Anova test, and the "independent sample T-test" was evaluated from which group the difference originated. Mountain plot and Blant-Altman plot analyses were used to compare methods. 95% confidence interval and statistical significance limit were accepted as p=0.05. Correlation, regression, distribution, method comparison, and multivariate analysis graphics were prepared with MedCalc.

Results

Measurements were performed on the left eye of 64 cases. Of these cases, 32 (50%) were female. The average age was 53.36±10.20 years (31–80 years). The demographic distribution and characteristics of the cases are summarized in Table 1. A statistically significant difference was found between the mean age, RNFL, and SAP-MD values between the groups. No statistically significant difference was found between sex

Table 1. Demographic distribution and characteristic features of cases

	POAG (n=33)	Healthy (n=31)	Total (n=64)	p*
Sex Distribution Female ratio	17/33	15/31	32/64	0.91 (Chi-square)
Mean Age	57.48±10.51 years	48.96±7.89 years	53.36±10.20 years	0.001
CCT	561.39±46.12 µ	561.70±45.31	561.54±45.36 µ	0.98
RNFL-T	76.60±12.74 µ	100.39±9.24 µ	88.12±16.33 µ	0.001
SAP-MD	-10.64±7.94 Db	-2.00±1.1 Db	-6.48±7.16 Db	0.001
NCT (IOP1)	15.72±3.02 mmHg	15.80±3.99 mmHg	15.76±3.49 mmHg	0.93
DCT (IOP2)	17.84±3.29 mmHg	17.95±3.86 mmHg	17.89±3.55 mmHg	0.91
GAT (IOP3)	16.48±3.41 mmHg	16.29±4.14 mmHg	16.39±3.75 mmHg	0.84
OPA	2.54±1.14 mmHg	2.57±0.94 mmHg	2.56±1.04 mmHg	0.89

*: Independent T-test between groups; RNFL: Retinal nerve fiber layer- thickness; CCT: Central corneal thickness; POAG: Primary open-angle glaucoma; n: number of cases; SAP-MD: Standard automated perimetry- mean deviation; dB: Decibel GAT: Goldman applanation tonometer, NCT: Non-contact tonometer, DCT: Dynamic contour tonometer; OPA: Ocular pulse amplitude.

distribution, IOP measurements of CCT, NCT, DCT, and GAT, and OPA values between the groups.

No statistically significant correlation was found between NCT, DCT, GAT, CCT, and mean age values among men and women. However, a statistically significant difference was found in the Pearson correlation test, in favor of women in OPA values (t=+2.022, p=0.047). On average, OPA was found to be 2.81±1.16 (0.7–5.4) and 2.30±0.84 (1–4.6) mmHg in women and men, respectively. No statistically significant correlation was found between age and CCT, NCT, GAT, DCT, and OPA values.

While a very strong and statistically significant correlation was found between CCT and NCT (p=0.000, r=0.568) and GAT (p=0.000, r=0.50), a positive, moderate, and statistically significant correlation (p=0.002, r=0.388) was found with DCT. No significant correlation was found between CCT and OPA (p=0.636).

While a positive, moderate, and statistically significant correlation was found between OPA and IOP, the most striking correlation was observed between OPA and DCT (r=0.401, p=0.001) and GAT (r=0.370, p=0.001) and NCT (r=0.364, p=0.001). A positive, strong, and statistically significant correlation was found between NCT, DCT, and GAT in all cases. The strongest correlation was observed between DCT and GAT (r=0.909, p=0.00), ranking between NCT and GAT (r=0.906, p=0.00), and between NCT and DCT (r=0.835, p=0.00) continued. Binary correlation analyses between the groups are summarized in Table 2. The correlation among all the three methods was excellent in both groups. While GAT and DCT have the strongest correlations in the control group, GAT and DCT and GAT and NCT were found to be similarly stronger than the DCT-NCT correlation in the POAG group.

NCT was not affected by age, gender, and the presence of POAG in linear regression analysis (p=0.312, p=0.440, p=0.929, respectively). A strong and statistically significant relationship was found between NCT and CCT (F=29.55, p=0.00). Similarly, in the multiple regression analysis, a strong, positive relationship was found only with CCT (r=0,568, p<0.001).

Linear regression analysis showed that the DCT was not affected by age, gender, and the presence of POAG (p=0.995, p=0.423, p=0.912, respectively). A positive, moderate relationship was observed between DCT and CCT (F=10.95, p=0.002). Similarly, a positive, moderate, and statistically significant relationship was observed only with CCT in multiple regression analysis (r=0.388, p=0.002).

In the linear regression analysis of the GAT, as observed, the age, gender, and the presence of POAG was not significantly affected (p=0.830, p=0.221, p=0.838 respectively). A positive, strong relationship was found between GAT and CCT (F=20.10, p<0.001). Similarly, in multiple regression analysis, a positive, moderate-strong relationship was observed only with CCT (r=0.495, p<0.001).

In the linear regression analysis, OPA was not affected by age, CCT, and presence of control-POAG (p=0.447, p=0.636, p=0.894, respectively). OPA was observed to have a positive and weak relationship with women (F=4.08, p=0.047). Similarly, in multiple regression analyses, only a significant relationship was found between OPA and gender with a weak favor in women (r=0.249, p=0.001).

In multiple regression analyses, all measurement methods were statistically significantly related to CCT. Because of this, the corneas were divided into three groups, "thin," "medium," and "thick," respectively (Table 3). NCT, GAT, DCT, and OPA values were compared using one-way analysis of variance and post-hoc test in all cases. OPA was not statistically different among the three groups (p=0.245). A statistically significant difference was found among the three corneal groups in all of NCT, DCT, and GAT. Based on the post-hoc test result, the group with CCT >580 μ (thick) was found to be the group that made the difference among the three corneal groups in all IOP measurement techniques (Table 4).

When control and POAG cases were divided into thin,

Table 2. Binary correlations of GAT / DCT / NCT in Control / POAG groups

Control/POAG	GAT/DCT	GAT/NCT	DCT/NCT
Control	r=0.939	r=0.878	r=0.836
n=31	p<0.001	p<0,001	p<0.001
	%95 CI:0.876-0.970	%95 CI:0,760-0,924	%95 CI:0.685-0.918
POAG	r=0.878	r=0.879	r=0.743
n=33	p<0.001	p<0.001	p<0.001
	%95 CI: 0.744-0.932	%95 CI: 0.767-0.939	%95 CI: 0.537-0.866

POAG: Primary open-angle glaucoma; GAT: Goldman applanation tonometer; NCT: Non-contact tonometer; DCT: Dynamic contour tonometer; N: Number of cases; CI: Reliability range.

Table 3. Cross distribution of Control, POAG Groups and CCT's Thin, Medium and Thick Groups

Groups	CCT			
	Thin	Medium	Thick	Total
Control				
n	6	17	8	31
% total	19.4	54.8	25.8	100.0
POAG				
n	7	16	10	33
% total	21.2	48.5	30.3	100.0
Total				
n	13	33	18	64
% total	20.3	51.6	28.1	100.0

CCT: Central corneal thickness, POAG: Primary open-angle glaucoma
n: Number of cases.

medium, and thick groups according to CCT, no statistically significant difference was found in NCT, GAT, and OPA measurements in all CCT groups, while control and POAG cases with thick CCT measurements by DCT was found a significant difference (p=0.033). No significant difference was found between the control and POAG in the thin and moderate CCT groups measured by DCT (Mann-Whitney U test, p>0.05). Moreover, no statistically significant difference in distribution according to CCT was observed between control and POAG cases using the Pearson Chi-Square test (p=0.875). The distribution of groups, according to CCT, is summarized in Table 3.

Comparison of Methods

GAT was accepted as the reference IOP measurement method. Reliability ranges and mean deviations were calculated in IOP measurement using all three methods in all corneal thickness (method comparison, Bland-Altman plot, mountain plot, MedCalc). The lower and upper values between GAT and NCT are -4.6 to +4.0 mmHg, and the median value is calculated as +0.7 mmHg. The lower and upper values between GAT and DCT were between -4.7 and +2.9 mmHg, and the median value was calculated as -1.45 mmHg.

The lowest and upper values between GAT and NCT in the control group were -4.6 to +2.7 mmHg, and the median value was calculated as +0.7 mmHg. With 95% reliability, GAT was observed to measure an average of 0.7 mmHg higher than NCT.

The lowest and upper values between GAT and DCT in the control group were -4.7 to +0.7 mmHg, and the median value was calculated as -1.5 mmHg. In 95% reliability, GAT was observed to measure 1.5 mmHg lower than DCT on average.

The lowest and upper values between GAT and NCT in the POAG group were -2.6 to +4.0 mmHg, and the median value was calculated as +0.7 mmHg. With 95% reliability, GAT was observed to measure an average of 0.7 mmHg higher than NCT.

The lowest and upper values between GAT and DCT in the POAG group were -3.9 to +2.9 mmHg, and the median value was calculated as -1.4 mmHg. With 95% reliability, GAT was observed to measure 1.4 mmHg lower than DCT on average.

When methods are compared with different corneal thicknesses using the Bland-Altman plot analysis, the highest difference was observed to be DCT-NCT difference in thin corneas. The least difference was the GAT-NCT difference in thick corneas. Table 5 summarizes the differences of methods in different thickness corneas.

Discussion

Ensuring that the value we obtain in the IOP measurement is the actual IOP is a significant problem. CCT is one of the main reasons for this problem because Goldmann made presentations of his designed tonometer and stated that there are factors that could potentially affect the applanation tonometer. Goldmann and Schmidt emphasized that

Table 4. Comparison of measurements in groups of different corneal thicknesses, and determination of the cornea group that makes a difference

Variables	ANOVA*	post-Hoc test (p)		
		Thin- Medium	Thin-Thick	Medium-Thick
DCT	p=0.003, F=6.37	0.814	0.017	0.001
GAT	p<0.001, F=7.88	0.514	0.002	0.001
NCT	p<0.001, F=12.26	0.152	<0.001	<0.001
OPA	p=0.245			

*: between three corneal groups, GAT: Goldman applanation tonometer, NCT: Non-contact tonometer, DCT: Dynamic contour tonometer, OPA: Ocular pulse amplitude.

Table 5. Comparison of the Methods in order to their thicknesses with CCT Groups (Bland and Altman Plot)

	Groups acc. to CCT			
	CCT<520µ (n=13)	520µ<CCT<580µ (n=33)	CCT>580µ (n=18)	Total (n=64)
Mean. Dif. (mmHg)				
GAT-DCT (mmHg)	-2.31±1.50	-1.36±1.24	-1.17±2.00	-1.51±1.57
%95 CI	-3.22-1.40	-1.80-0.93	-2.70-0.18	-1.90-1.11
GAT-NCT (mmHg)	1.23±1.59	0.49±1.54	0.46±1.66	0.63±1.55
%95 CI	0.26–2.19	0.06–1.03	-0.32–1.29	0.23–1.03
DCT-NCT (mmHg)	3.54±1.90	1.85±2.00	1.69±1.77	2.14±2.02
%95 CI	2.39-4.70	1,14-2.56	0.76-2.52	1.63–2.64

DCT: Dynamic contour tonometer, GAT: Goldmann applanation tonometer, NCT: Non-contact tonometer CCT: Central corneal thickness, CI: Confidence interval, mmHg: millimeter mercury, µ: micron, n: Number of cases.

there is an interaction between corneal thickness and IOP measurement with applanation tonometers and called attention to 500 µm threshold value in CCT. They reported that the measurements in sub-threshold or above-threshold thicknesses might be erroneous (18). Ehlers et al. (19) made IOP measurements with intracamerally inserted cannulae in patients undergoing cataract surgery and reported that the IOP value obtained using the manometer was most compatible with the GAT in corneas at 520 µm levels. Although GAT is the gold standard today, its drawbacks cannot be ignored. The fact that there are many identified sources of error has not changed it to be a reference tonometer simply has led many scientists to the search for the development of a more practical tonometer, which is ideal, minimally affected by external factors and more clinically useful. NCTs also measure IOPs with the help of a computer, providing the force required for applanation with air pulses and proportionally with the applanation time, without the need for contact to the cornea. Similarly, both measurement methods required a reliable tonometer that is not affected by the cornea's biomechanics due to reasons including ocular rigidity, CCT, and the ability of the aqueous to make erroneous measurements due to the escape from the trabecula, albeit minimally in repetitive measurements, and increased prevalence of refractive surgery today. Pascal DCT is a digital tonometer developed by Kangiesser and Robert, which is compatible with the cornea and can measure the pressure directly without deforming the cornea, thanks to the sensing tip surface that coincides with the curvature of the outer surface of the cornea (14,16,17).

Boehm et al. (20) evaluated 75 patients who underwent cataract surgery and performed IOP measurements by preoperative DCT and perioperative intracameral manometer methods of patients. When IOP values were at the levels of 15 mmHg, 20 mmHg, and 35 mmHg, the differences of the measurements with DCT were found to be 0.02, -0.2, and -0.8, respectively, and concluded that it made a close measurement with almost manometric value. Pepose et al. (21) reported that in the eyes that underwent LASIK surgery with an average ablation of 90 microns, IOP measurements using DCT was 0.5 mmHg lower, but this difference was not statistically significant. In the same study, when IOP measurements were performed using GAT, this difference was reported as 1.8 mmHg and significant. They concluded that DCT was not affected by corneal biomechanics.

Several studies in the literature compared DCT and GAT. In these studies, the DCT-GAT difference was reported as -0.46 to 3.88 (mean: 1.74) mmHg (22–37,62–66).

In our study, this difference is 1.51 mmHg and is compatible with the literature.

The mean IOP measured using GAT, DCT, and NCT was 16.39±3.75 mmHg, 17.89±3.55 mmHg, and 15.76±3.49 mmHg, respectively. While this difference between GAT and NCT was not statistically significant (p=0.33), this difference between DCT and GAT and NCT was statistically significant (p=0.02, p<0.001, respectively). In the literature, studies show that DCT measures higher than GAT and NCT (24,25,28-30,33,35,63-65).

Compared with GAT, DCT, and NCT in all subjects, GAT was observed to measure 0.7 mmHg higher than NCT on average. Although different studies on this subject exist in the literature, NCT measures a small amount higher than GAT is often the consensus (31,38,39). However, differences may be present since NCTs have different designs and calibrations. In a few studies with Pulsair IntelliPuff, which was used in our study, Kelechi et al. (38) and Parker et al. (39) reported

that NCT measured somewhat lower than GAT. A comparison of Pulsair IntelliPuff TM NCT versus Pascal DCT in the literature has not been reported before as far as we know.

When the compatibility of GAT, DCT, and NCT was examined, a positive and strong correlation between GAT and DCT and NCT was found. While the relationship between GAT and DCT was found to be the strongest, GAT and NCT, and DCT and NCT were relatively weaker, respectively. Several studies in the literature showed that the correlation between GAT and DCT is excellent (22,23,25-27,31,32,35,38-41,62,63,66). When the binary correlations between GAT, DCT, and NCT methods in the control and POAG groups were examined, the correlations between them were strong in both groups. It was concluded that the presence of POAG did not affect the compatibility among the three methods. The differences in the control and POAG groups did not change either. In the control group, the mean GAT-NCT difference was 0.7 mmHg, and the GAT-DCT difference was -1.5 mmHg. Additionally in the POAG group, the GAT-NCT difference was averaged at 0.7 mmHg, and the GAT-DCT difference was -1.4 mmHg. The presence of POAG did not affect the mean difference among the measurements of these three methods. During measuring using all the three methods, the consensus is that it is not affected by the presence of glaucoma (24,27,28,62-64).

In this study, when the relationship between POAG presence, CCT, age, and gender, GAT, DCT, and NCT measurements was examined using both simple linear and multiple regression analyses, GAT was observed to have a statistical relationship with CCT only. Similarly, the relationship between NCT and CCT was observed to be stronger than the relationship between GAT and CCT (21,23,28,32,33,35,38-40). A moderate relationship was observed in the DCT only with CCT. The findings support this result, when the cases were divided into thin, medium, and thick groups according to their corneal thicknesses. The "thick" group with CCT >580 μ was observed to affect all measurements in all three methods. This difference was most pronounced in NCT than in GAT and, lastly, in DCT. The course of these findings is consistent with the literature for GAT, and NCT (27,40-43) is generally in contrast to the literature about DCT. Both the manufacturer and several researchers claim that DCT is not affected by CCT, but DCT is particularly affected by thick corneas. Few supporting studies are also available (21,28,30,31,35,65). The relationship between CCT and GAT and NCT was more linear than DCT. GAT had a tendency to give higher IOP readings than NCT in all corneal thicknesses; this difference was less in medium and thick corneas (0.49±1.54 and 0.46±1.66, respectively), but in thin corneas, it was higher (1.23±1.59). This study showed that the DCT tended to measure higher in all corneas than GAT, the difference between them decreased as the thickness of the cornea increased, and the difference between them was the most prominent in the thin corneas (2.31±1.50). This difference was reduced in the medium and thick corneas (1.36±1.24 and 1.17±2.00, respectively). The difference between the DCT and the GAT (mean 1.51±1.57) was very compatible with the literature; the difference in thick corneas was less. Andreanos et al. (65) found the difference as 3.88±2.8 mmHg in their study on 185 eyes and stated that this difference was the most prominent in thin corneas. Several studies in the literature support this direction (22,24, 26,28-33,35,36,38-44,65).

Choroid is an indirect marker of the circulation and gives an idea of perfusion in the eye during the cardiac cycle (45,46,61). Since decreased perfusion may cause hypoxia and damage to nerve fibers, it can provoke progression in anterior ischemic optic neuropathy and glaucoma-like diseases. Von Schulthess et al. (67) found correlations between low OPA and rapid progressive glaucoma in his series with 14 cases.

In our study, findings showed the mean of OPA as 2.55±1.04 (0.7-5.4) mmHg in all cases. This average was reported in the literature as 2.3–3.3 (average 2.87) mmHg (22,28,32,42,48-55). No statistically significant difference was found between the two groups. We thought that all our glaucoma patients who received anti-glaucomatous treatment prevented the difference between the averages. In a large study conducted by Punjabi et al. (56) in their 906 eyes series, the average OPA value in 52 eyes with ocular hypertension was 3.61 mmHg and 3.00 mmHg in 501 eyes with POAG and was reported higher in OHT eyes than in glaucomatous and healthy control eyes. However, in that study, POAG patients are under anti-glaucomatous treatment, and OPA may be averaged due to treatment. Topical glaucoma treatments have been reported to affect the OPA value (50,57). Figueiredo et al. (64) reported an OPA value of 3.4±1.2 mmHg in glaucoma patients with newly diagnosed and untreated glaucoma, and 2.6±0.9 mmHg in the healthy control group. In our study, a statistically positive, moderate, and significant correlation was found between OPA and IOP. With an increase in IOP, the scleral surface tension increases, and increasing blood volume with systole causes an increase in pressure rather than stretching on the scleral surface under tension. The relationship between IOP and OPA can be supported by this theory (58,61,63). Centofanti et al. (59) reported that perfusion in the eye may be affected by gender and hormones and that OPA is higher in premenopausal women than those in the menopausal period. Similarly, Perkins reported that it was higher in women (60). In our study, the OPA values in women were found to be significantly higher, but Kaufmann et al. found that OPA

was not affected by gender in control cases (48). Since OPA may be different in different glaucoma types, they may have specific values according to the glaucoma type. However, the situation is not clear. No complete consensus was found in the literature on what is the appropriate value of OPA and what factors change OPA. However, new studies may reveal the absolute clinical meaning and the possible importance of OPA.

Conclusion

In our study, all of the three methods were compared in both POAG and control cases and different corneal thickness groups in detail. The measurements of IOP were found to be quite correlated with both DCT and GAT. DCT was observed to be minimally affected by corneal thickness; this effect was much less in thin corneas. DCT measured IOP higher in thin corneas than GAT, especially in cases affected by corneal factors (i.e., previous refractive surgery), IOP measurement using DCT can be valuable. It can be used in glaucoma diagnosis and follow-up. Pulsair IntelliPuff® NCT is easy to use clinically, it has the advantage of being portable, and it is possible to measure even in immobilized patients. However, it should not be preferred to GAT and DCT in the diagnosis and in the follow-up of glaucoma as it is more affected by CCT. GAT is still the gold standard for IOP measurement. GAT is significantly dependent on corneal thickness and other biomechanical parameters of the cornea and can measure IOP lower in the eyes with thin cornea and higher in the eyes with thick cornea. Adjusting the IOP, according to CCT, will not eliminate the effect of CCT. DCT was developed for noninvasive and direct IOP measurement, and it can measure IOP quite accurately and is minimally affected by corneal thickness or corneal elasticity. It also provides a report of measurement quality by itself. However, it also allows for OPA and diastolic IOP measurement. Its weaker aspects are its longer measurement time and it require more patient compliance. In our study, DCT was also observed to make high measurements on thick corneas. Today, normative IOP values in the diagnosis and follow-up of glaucoma is based on the measurements made with GAT. Measurements made with DCT should considered to differ from these normative values, and the threshold value should be revised. Comparative clinical studies with prospective, larger case series may be guiding..

Disclosures

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References

1. Ozcetin H. Göz tansiyonu, glokom tanısı ve tipleri. 2nd ed. Göz tansiyonu ve glokomlar. İstanbul: Nobel Tıp Kitabevi; 2009. p. 343.
2. Flammer J, Orgül S, Costa VP, Orzalesi N, Krieglstein GK, Serra LM, et al. The impact of ocular blood flow in glaucoma. Prog Retin Eye Res 2002;21:359–93.
3. Watson PG, Jakeman C, Ozturk M, Barnett MF, Barnett F, Khaw KT. The complications of trabeculectomy (a 20-year follow-up). Eye (Lond) 1990;4:425–38.
4. Yanoff M, Duker J S. Ophtalmology. 2nd ed Türkçe baskı. İstanbul: Hayat Tıp Kitabevi; 2007. p. 1535–610.
5. Kanski J. Kanski's Clinical Ophtalmology. 8th ed. Philadelpiha: Elsevier; 2016. P.306–58.
6. Bengisu Ü: Göz Hastalıkları. 4th ed. Glokom. Ankara: Palme Yayınevi; 1998. p:139–58
7. Budenz DL, Anderson DR, Feuer WJ, Beiser JA, Schiffman J, Parrish RK 2nd, et al; Ocular Hypertension Treatment Study Group. Detection and prognostic significance of optic disc hemorrhages during the Ocular Hypertension Treatment Study. Ophthalmology 2006;113:2137–43.
8. Hoskins Jr HD, Kass M. Primary open angle glaucoma, Becker-Shaffers Diagnosis and Therapy of the Glaucomas. 6th Ed. Maryland Heights: Mosby 1989. p. 277–301.
9. Kaufman PL, Mittag TW. Epidemiology of open-angle glaucoma. In: Podos SM, Yanoff M, editors. Textbook of Ophthalmology. 7th ed. London: Mosby; 1994. p. 8.29–8.33.
10. Schottenstein EM. Intraocular pressure and tonometry. In: Ritch R, Shields MB, Krupin T, editors. The Glaucomas – Basic Sciences. 2nd ed. St. Louis: Mosby; 1996. p. 407–28.
11. Krupin T. Methods of measuring intraocular pressure. Manual of Glaucoma. New York: Churchill Livingstone; 1988. p. 7–18.
12. Ozcetin H. Klinik göz hastalıkları; göziçi basıncı ve glokomlar: B1. 6th Ed. İstanbul: Nobel Tıp kitabevi; 2003. p. 137–82.
13. Ozcetin H. Göziçi basıncı ölçümü ve tonometreler. Göz tansiyonu ve glokomlar. 2nd ed. İstanbul: Nobel Tıp Kitabevi; 2009. p. 55–99.
14. Kniestedt C, Nee M, Stamper RL. Accuracy of dynamic contour tonometry compared with applanation tonometry in human cadaver eyes of different hydration states. Graefes Arch Clin Exp Ophthalmol 2005;243:359–66.
15. Kanngiesser HE, Nee M, Kniestedt C, Inversini C, Stamper RL. The theoretical foundations of dynamic contour tonometry. Poster presented at: The Annual Meeting of the Association for Research in Vision and Ophthalmology. May 6, 2003; Fort Lauderdale, FL.
16. SMT Swiss Microtechnology AG. Pascal Dynamic Contour To-

nometer Operating Manuel, version 1.4 2004:30–2.
17. Kanngiesser HE, Kniestedt C, Robert YCA. Dynamic Contour Tonometry: Presentation of a New Tonometer. J Glaucoma 2005;14:344–50.
18. Goldmann H, Schmidt T. Über Applanationstonometrie. Ophthalmologica 1957;134:221–42.
19. Ehlers N, Bramsen T, Sperling S. Applanation tonometry and central corneal thickness. Acta Ophthalmol 1975;53:34–43.
20. Boehm AG, Weber A, Pillunat LE, Koch R, Spoerl E. Dynamic contour tonometry in comparison to intracameral IOP measurements. Invest Ophthalmol Vis Sci 2008;49:2472–7.
21. Pepose JS, Feigenbaum SK, Qazi MA, Sanderson JP, Roberts CJ. Changes in corneal biomechanics and intraocular pressure following LASIK using static, dynamic, and noncontact tonometry. Am J Ophthalmol 2007;143:39–47.
22. Hoffmann EM, Grus FH, Pfeiffer N. Intraocular pressure and ocular pulse amplitude using dynamic contour tonometry and contact lens tonometry. BMC Ophthalmology 2004;4:4–11.
23. Kaufmann C, Bachmann LM, Thiel MA. Comparison of Dynamic Contour Tonometry with Goldmann Applanation Tonometry. Investigative Ophthalmology & Visual Science 2004;45:3118–21.
24. Kamppeter BA, Jonas JB. Dynamic contour tonometry for intraocular pressure measurement. Am J Ophthalmol 2005;140:318–20.
25. Burvenich H, Burvenich E, Vincent C. Dynamic Contour Tonometry (DCT) Versus Non-Contact Tonomtry (NCT): A Comparıson Study. Bull Soc belge Ophtalmol 2005;298:63–9.
26. Pache M, Wilmsmeyer S, Lautebach S, Funk J. Dynamic contour tonometry versus Goldmann applanation tonometry: a comparative study. Graefe's Arch Clin Exp Ophthalmol 2005;243:763–67.
27. Barleon L, Hoffmann EM, Berres M, Pfeiffer N, Grus FH. Comparison of dynamic contour tonometry and goldmann applanation tonometry in glaucoma patients and healthy subjects. Am J Ophthalmol 2006;142:583–90.
28. Ku JY, Danesh-Meyer HV, Craig JP, Gamble GD, McGhee CN. Comparison of intraocular pressure measured by Pascal dynamic contour tonometry and Goldmann applanation tonometry. Eye (Lond) 2006;20:191–8.
29. Schneider E, Grehn F. Intraocular pressure measurement-comparison of dynamic contour tonometry and goldmann applanation tonometry. J Glaucoma 2006;15:2–6.
30. Öztürk F, Kusbeci T, Ermiş SS, Kaplan U, Inan UU. Pascal Dinamik Kontur Tonometre ile Ölçülen Göz içi Basınç Değerlerinin Goldmann Applanasyon Tonometresi, Non Kontakt Tonometre ve Tonopen ile Karşılaştırılması ve Santral Kornea Kalınlığının Etkisi. Journal of Glaucoma-Cataract 2006;1:171–5.
31. Pelit A, Altan-Yaycioglu R, Akova AY. Effect of corneal thickness on intraocular pressure measurements with the Pascal dynamic contour, Canon TX-10 non-contact and Goldmann applanation tonometers in healthy subjects. Clin Exp Optom 2009;92:14–18.
32. Özçetin H. Atasoy. Pascal dinamik kontür tonometre ile Goldmann aplanasyon tonometrelerin karşılaştırılması. Göz tansiyonu ve glokomlar. 2nd ed. İstanbul: Nobel Tıp kitabevi; 2009. p. 83–101.
33. Salvetat ML, Zeppieri M, Tosoni C, Brusini P. Comparisons between Pascal dynamic contour tonometry, the TonoPen, and Goldmann applanation tonometry in patients with glaucoma. Acta Ophthalmol Scand 2007;85:272–9.
34. Herdener S, Pache M, Lautebach S, Funk J. Dynamic contour tonometry (DCT) versus Goldmann applanation tonometry (GAT) - a comparison of agreement and reproducibility. Graefes Arch Clin Exp Ophthalmol 2007;245:1027–30.
35. Lee J, Lee CH, Choi J, Yoon SY, Sung KR, Park SB, et al. Comparison between dynamic contour tonometry and Goldmann applanation tonometry. Korean J Ophthalmol 2009;23:27–31.
36. Pourjavan S, Boëlle PY, Detry-Morel M, De Potter P. Physiological diurnal variability and characteristics of the ocular pulse amplitude (OPA) with the dynamic contour tonometer (DCT-Pascal). Int Ophthalmol 2007;27:357–60.
37. Detry-Morel M, Jamart J, Detry MB, Ledoux A, Pourjavan S. Clinical evaluation of the Pascal dynamic contour tonometer. J Fr Ophtalmol 2007;30:260–70.
38. Ogbuehi KC, Almubrad TM. Accuracy and reliability of the Keeler Pulsair EasyEye non-contact tonometer. Optom Vis Sci 2008;85:61–6.
39. Parker VA, Herrtage J, Sarkies NJC. Clinical comparison of the Keeler Pulsair 3000 with Goldmann applanation tonometry. Br J Ophthalmol 2001;85:1303–4.
40. Doyle A, Lachkar Y. Comparison of dynamic contour tonometry with Goldman applanation tonometry over a wide range of central corneal thickness. J Glaucoma 2005;14:288–92.
41. Burvenich H, Burvenich E, Vincent C. Dynamic contour tonometry (DCT) versus non-contact tonometry (NCT): a comparison study. Bull Soc Belge Ophtalmol 2005:63–9.
42. Kniestedt C, Lin S, Choe J, Nee M, Bostrom A, Stürmer J, et al. Correlation between intraocular pressure, central corneal thickness, stage of glaucoma, and demographic patient data: prospective analysis of biophysical parameters in tertiary glaucoma practice populations. J Glaucoma 2006;15:91–7.
43. Yasar T, Yener IH, Demirok A. Normal Santral Kornea Kalınlıklı Bireylerde Göz içi Basıncı Ölçümünde Goldmann Aplanasyon Tonometri ile Dinamik Kontur Tonometrinin Karsılastırılması. J of Glaucoma-Cataract 2007;2:241–44.
44. Erdurmus M, Totan Y, Yagci R, Aydin D, Hepsen F. Primer Açık Açılı Glokom ve Oküler Hipertansiyonda Dinamik Kontur Tonometre ve Non-Kontakt Tonometrenin Karsılastırılması. Turkiye Klinikleri J Ophthalmol 2007;16:108–113.
45. Langham ME, To'Mey KF. A clinical procedure for the measurements of the ocular pulse-pressure relationship and ophthalmic

arterial pressure. Exp Eye Res 1978;27:17–25.
46. Silver DM, Farrell RA. Validity of pulsatile ocular blood flow measurements. Surv Ophthalmol 1994;38:72–80.
47. Weizer JS, Asrani S, Stinnett SS, Herndon LW. The clinical utility of dynamic contour tonometry and ocular pulse amplitude. J Glaucoma 2007;16:700–3.
48. Kaufmann C, Bachmann LM, Robert YC, Thiel MA. Ocular pulse amplitude in healthy subjects as measured by dynamic contour tonometry. Arch Ophthalmol 2006;124:1104–8.
49. Viestenz A, Langenbucher A, Viestenz A. Reproducibility of Dynamic Contour Tonometry. Comparison with TonoPenXL and Goldmann Applanation Tonometry-A Clinical Study on 323 Normal Eyes. Klin Monatsbl Augenheilkd 2006;223:813–19.
50. Fuchsjäger-Mayrl G, Wally B, Rainer G, Buehl W, Aggermann T, Kolodjaschna J, et al. Effect of dorzolamide and timolol on ocular blood flow in patients with primary open angle glaucoma and ocular hypertension. Br J Ophthalmol 2005;89:1293–7.
51. Weizer JS, Asrani S, Stinnett SS, Herndon LW. The Clinical Utility of Dynamic Contour Tonometry and Ocular Pulse Amplitude. J Glaucoma 2007;16:700–03.
52. Villas-Bôas FS, Doi LM, Sousa AKS, Melo Jr LAS. Correlation between diurnal variation of intraocular pressure, ocular pulse amplitude and corneal structural properties. Arq Bras Oftalmol 2009;72:296–301.
53. Grieshaber MC, Katamay R, Gugleta K, Kochkorov A, Flammer J, Orgul S. Relationship between ocular pulse amplitude and systemic blood pressure measurements Acta Ophthalmol 2009;87:329–34.
54. Stalmans I, Harris A, Vanbellinghen V, Zeyen T, Siesky B. Ocular pulse amplitude in normal tension and primary open angle glaucoma. J Glaucoma 2008;17:403–7.
55. Carbonaro F, Andrew T, Mackey DA, Spector TD, Hammond CJ. The heritability of corneal hysteresis and ocular pulse amplitude: a twin study. Ophthalmology 2008;115:1545–9.
56. Punjabi OS, Ho HK, Kniestedt C, Bostrom AG, Stamper RL, Lin SC. Intraocular pressure and ocular pulse amplitude comparisons in different types of glaucoma using dynamic contour tonometry. Curr Eye Res 2006;31:851–62.
57. Zeitz O, Matthiessen ET, Reuss J, Wiermann A, Wagenfeld L, Galambos P, et al. Effects of glaucoma drugs on ocular hemodynamics in normal tension glaucoma: a randomized trial comparing bimatoprost and latanoprost with dorzolamide [ISRCTN18873428]. BMC Ophthalmol 2005;5:6.
58. Silver DM, Geyer O: Pressure volume relation for the living human eye. Curr Eye Res 2000;20:115–20.
59. Centofanti M, Bonini S, Manni G, Guinetti-Neuschüler C, Bucci MG, Harris A. Do sex and hormonal status influence choroidal circulation? Br J Ophthalmol 2000;84:786–7.
60. Perkins ES. The ocular pulse. Curr Eye Res 1981;1:19–23.
61. Willekens K, Rocha R, Van Keer K, Vandewalle E, Abegão Pinto L, Stalmans I, et al. Review on Dynamic Contour Tonometry and Ocular Pulse Amplitude. Ophthalmic Res 2015;55:91–8.
62. Morita T, Shoji N, Kamiya K, Hagishima M, Fujimura F, Shimizu K. Intraocular pressure measured by dynamic contour tonometer and ocular response analyzer in normal tension glaucoma. Graefes Arch Clin Exp Ophthalmol 2010;248:73–7.
63. Cheng L, Ding Y, Duan X, Wu Z. Ocular pulse amplitude in different types of glaucoma using dynamic contour tonometry: Diagnosis and follow-up of glaucoma. Exp Ther Med 2017;14:4148–52.
64. Figueiredo BP, Cronemberger S, Kanadani FN. Correlation between ocular perfusion pressure and ocular pulse amplitude in glaucoma, ocular hypertension, and normal eyes. Clinical Ophthalmology 2013;7:1615–21.
65. Andreanos K, Koutsandrea C, Papaconstantinou D, Diagourtas A, Kotoulas A, Dimitrakas P, et al. Comparison of Goldmann applanation tonometry and Pascal dynamic contour tonometry in relation to central corneal thickness and corneal curvature. Clin Ophthalmol 2016;10:2477–84.
66. Anderson MF, Agius-Fernandez A, Kaye SB. Comparison of the Utility of Pascal Dynamic Contour Tonometry with Goldmann Applanation Tonometry in Routine Clinical Practice J Glaucoma 2013;22:422–6.
67. von Schulthess SR, Kaufmann C, Bachmann LM, Yanar A, Thiel MA. Ocular pulse amplitude after trabeculectomy. Graefes Arch Clin Exp Ophthalmol 2006;244:46–51.