The Comparison of Dynamic Contour Tonometry with Goldmann Applanation Tonometry, Non-Contact Tonometry and Tono-Pen; and the Association of Measurements with Ocular Structures

Dinamik Kontür Tonometrenin Goldmann Applanasyon Tonometre, Non-Kontakt Tonometre ve Tono-Pen ile Karşılaştırılması ve Gözün Yapısal Özelliklerinin Ölçümlerle İlişkisi

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ABSTARCT

Purpose: To compare the intraocular pressure (IOP) measured by dynamic contour tonometry (DCT), Goldmann applanation tonometry (GAT), non-contact tonometry (NCT) and Tono-Pen and also to assess whether ocular parameters such as corneal thickness, keratometry and axial length affect the measurements by the tonometers.

Materials and Methods: One hundred healthy subjects prospectively underwent IOP measurement with DCT, GAT, NCT and Tono-Pen. The correlation between the tonometer readings as well as the effect of keratometry, central corneal thickness (CCT), axial length and anterior chamber depth on IOP measurements were assessed.

Results: DCT readings were higher than NCT (ΔIOP=2.0±3.2 mmHg, p<0.001) and GAT (ΔIOP=1.3±2.1 mmHg, p=0.003) but not Tono-Pen (ΔIOP=0.1±2.7 mmHg, p=0.981). DCT, GAT and NCT correlated positively with CCT (p=0.039, p=0.020 and p=0.001). GAT and NCT readings were significantly higher in eyes with thick cornea (>568 µm) compared to eyes with thin cornea (<535 µm) (p=0.021 and p=0.003). Ocular parameters other than CCT did not have a significant effect on the readings of tonometers.

Conclusion: Despite significant correlation; DCT readings were higher than GAT and NCT but not Tono-Pen. DCT, NCT and GAT readings significantly correlated with CCT. GAT and NCT readings were significantly higher in eyes with thick cornea compared to eyes with thin cornea.

Key Words: Dynamic contour tonometry, Goldmann applanation tonometry, non-contact tonometry, pascal tonometry, Tono-Pen.

ÖZ

Amaç: Dinamik kontür tonometre (DKT), Goldmann applanasyon tonometre (GAT), non-kontakt tonometre (NKT) ve Tono-pen ile ölçülen göz içi basınçlarının (GİB) kıyaslanması ve santral korneal kalınlık (SKK), keratometri ve aksiyel uzunluk gibi oküler parametrelerin tonometre ölçümlerine olan etkilerinin araştırılması.

Gereç ve Yöntem: Prospektif olarak gerçekleştirilen çalışmada, 100 sağlıklı erişkinin GİB ölçümleri DKT, GAT, NKT ve Tono-pen ile gerçekleştirildi. Tonometre ölçümlerinin birbirleriyle korelasyonuna ek olarak, keratometri, SKK, aksiyel uzunluk ve ön kamara derinliğinin GİB ölçümlerine olan etkisi araştırıldı.

Bulgular: DKT ölçümleri NKT (ΔIOP=2.0±3.2 mmHg, p<0.001) ve GAT (ΔIOP=1.3±2.1 mmHg, p=0.003) ölçümlerinden daha yüksek saptanırken, Tono-pen (ΔIOP=0.1±2.7 mmHg, p=0.981) ölçümleriyle arasında anlamlı bir fark izlenmedi. DKT, GAT, NCT ve SKK arasında pozitif yönde bir korelasyon saptandı (p=0.039, p=0.020 and p=0.001). GAT ve NKT ölçümleri kalın kornealarda (>568 µm), ince kornealara (<535 µm) göre daha yüksek izlendi (p=0.021 and p=0.003). SKK dışındaki oküler parametrelerin tonometre ölçümleri üzerine anlamlı bir etkisi saptanmadı.

Sonuç: Tonometriler arasındaki anlamlı korelasyona ragmen, DKT ölçümlerinin GAT ve NKT'den daha yüksek olduğu, Tono-pen ölçümlerinden farklı olmadığı izlendi. DKT, GAT, NCT ve SKK arasında anlamlı bir korelasyon saptandı. GAT ve NKT ölçümlerinin kalın kornealarda ince kornealara göre daha yüksek olduğu görüldü.

Anahtar Kelimeler: Dinamik kontür tonometri, Goldmann applanasyon tonometri, non-kontakt tonometri, pascal tonometri, Tono-pen.

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INTRODUCTION

Dynamic contour tonometry (DCT), presented by Kangiesser et al.,[1], is a slit lamp mounted contact tonometer that uses a transcorneal method to measure intraocular pressure (IOP). A pressure sensor is embedded within the tonometer tip that matches the corneal contour, thus minimizing the amount of corneal deformation.[2] The DCT gathers 100 IOP readings per second over a 5- to 8-second period and records dynamic IOP. It was showed that DCT revealed good measurement precision, repeatability and reproducibility compared to Goldmann applanation tonometry (GAT).[3,4] Moreover, DCT provided IOP measurements which were less affected by corneal thickness compared to GAT.[5,6] It is suggested that DCT could be more accurate than GAT in patients with extreme pachymetry.[7]

The non-contact air tonometer (NCT) uses a puff of air directed at the cornea and is based on applanation principle. It is a widely used tonometer because of high patient tolerability due to lack of direct contact between the tonometer and the corneal surface.[8] Tono-Pen is a portable, handheld tonometer which is based on applanation principle but with a smaller applanation area than GAT.[9] It is the tonometer of choice in patients with corneal pathologies and in patients who can not tolerate other instruments such as children and the ones with developmental delay.[10] Both NCT and Tono-pen have been compared with GAT previously but little is known about the comparison of DCT, NCT and Tono-pen.

The objectives of this study are to compare the IOP measured by DCT with that measured by GAT, NCT and Tono-Pen and to assess whether ocular parameters such as corneal thickness, keratometry and axial length affect the measurements by DCT.

MATERIAL AND METHODS

This prospective study was conducted at the Department of Ophthalmology at a university setting after Institutional Review Board approval. All participants provided informed consent to participate in the study. One hundred eyes of 100 healthy subjects were enrolled in the study. Healthy subjects were recruited through hospital staff, patients and relatives of patients attending outpatient clinic.

Exclusion criteria were previous ocular history (corneal diseases, ocular inflammation, glaucoma, etc.), surgery or trauma. All participants had a complete ophthalmic examination including visual acuity measurement (using Snellen charts), anterior and posterior segment examinations by slit lamp biomicroscopy (with 90-D lens for posterior segment).

The tests were done in the following order: keratometry (K), IOP, systemic blood pressure (SBP), central corneal thickness (CCT), anterior chamber depth (ACD) and axial length (AL) measurements. All measurements were carried out by the same ophthalmologist and readings were done by another investigator.

Only the right eyes of the patients were included in the study to minimize the systemic bias. K was measured by a MRK-3100 premium auto-ref/keratometer (Huvitz Company, Gyeonggi-do, Korea).To minimize the confounding effect of diurnal fluctuation, all IOP measurements were taken within 20 minutes in a random order with DCT (Ziemer Ophthalmic Systems AG, CH-2562 Port, Switzerland), GAT (Goldmann applanation tonometer, H03,Haag-Streit, Switzerland), Tono-Pen (Medtronic Tono-Pen XL applanation tonometer, Medtronic Jacksonville, FL USA) and NCT (NT-2000 auto non-contact tonometer, Nidek, Japan). Topical Proparacaine 0.5% was instilled before each measurement.

DCT measurement was performed according to the methods that had been described previously and the measurements of acceptable quality (Q1 to 3) were recorded.[2,11] Tono-Pen readings with the standard deviation of the valid measurements 5% or less were recorded for analysis according to the manufacturer's guidelines (http://www.calcoastophthalmic.com/pdf/Tono-PenXLmanual.pdf).

SBP was measured after IOP measurements with a manual manometer. CCT was measured by ultrasonic pachymeter (Nidek UP 1000 ultrasonic pachymeter, Nidek.Co.Ltd, Japan) at the center of cornea. ACD and AL were measured by A-scan biometry with contact technique (Humphrey A/B Scan 835, Carl ZeissMeditec, Inc., USA). An average of 3 readings was recorded with each device for each participant. All measurements were taken during day time (10 am to 4 pm) and with the patient in a sitting position.

SPSS software (SPSS Institute Inc., Chicago, IL, USA) was used for statistical analysis. The normality of the tonometry distributions was determined by Shapiro-Wilk test. Kruskal-Wallis test was used for comparison of IOP readings between the tonometers. Spearman correlation coefficients were used to verify correlations among tonometry readings and the independent factors. The level of significance was set at $p<0.05$.

RESULTS

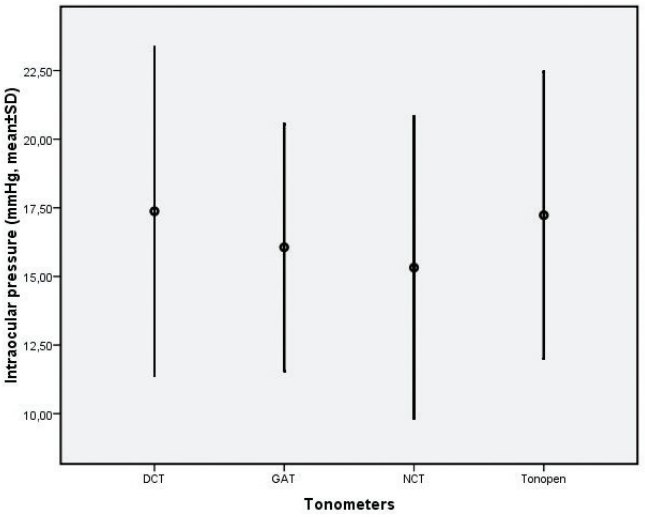
The study included 100 eyes of 100 hundred healthy subjects. The mean, minimum and maximum values of age, systemic BP and ocular characteristics of the patients are shown in table 1.

Table 1: *Clinical parameters of the subjects (mean±SD).*

Age (y)	35.7±15.2 (16-66)
DCT (mmHg)	17.3±2.9 (10.7-25.2)
GAT (mmHg)	16.1±2.2 (11-21)
NCT (mmHg)	15.3±2.7 (8-21)
Tono-Pen (mmHg)	17.2±2.6 (10-23)
OPA (mmHg)	2.3±0.9 (0.8-6.5)
AL (mm)	23.3±0.7 (22-25.6)
ACD (mm)	3.2±0.3 (2.5-4.1)
CCT (µm)	543.8±32.6 (465-661)
K (D)	43.6±1.2 (40.2-46.2)
SBP (mmHg)	118.8±9.3 (110-140)
DBP (mmHg)	75.8±5.1 (70-90)

DCT; Dynamic Contour Tonometry, GAT; Goldmann Applanation Tonometry,i NCT: Non-Contact Tonometry, OPA; Ocular Pulse Amplitude, AL; Axial Length, ACD; Anterior Chamber Depth CCT; Central Corneal Thickness, K; Keratometry, SBP; Systolic Blood Pressure, DBP; Diastolic Blood Pressure.
K values were available in 84 patients. N=100 for any parameter except K.

DCT readings were significantly higher than GAT and NCT but not Tono-Pen. Tono-Pen readings were also higher than GAT and NCT. GAT readings were not significantly different from NCT (Graphic 1). All tonometers showed a significant positive correlation which was more remarkable between DCT and GAT (Table 2). DCT, GAT and NCT correlated positively only with CCT but not other ocular parameters (Table 3). Graphic 2 shows the correlation between CCT and the readings of the tonometers. The eyes were grouped as with thin (<535 µm), intermediate (536-567 µm) and thick corneas (>568 µm) as previously described by Park et al.,[12] GAT and NCT readings were significantly higher in eyes with thick cornea compared to eyes with thin cornea (p=0.021 and p=0.003, post-hoc tukey). Tono-Pen and DCT readings did not change significantly according to the corneal thickness (p=0.187 and p=0.359).



Graphic 1: *Graph shows the mean intraocular pressure values measured by dynamic contour tonometry (DCT), Goldmann applanation tonometry (GAT), non-contact tonometry (NCT) and Tono-Pen. P values for the comparison of the measurements between the tonometers are as follows: p=0.003 for DCT and GAT, p<0.001 for DCT and NCT, p=0.777 for DCT and Tono-pen, p=0.101 for GAT and NCT, p<0.001 for Tono-pen and GAT, p<0.001 for Tono-pen and NCT (Kruskal Wallis).*

DISCUSSION

In our study, DCT readings were significantly higher than that of NCT and GAT but not Tono-Pen. The readings of DCT, NCT and GAT correlated with CCT. GAT and NCT readings were significantly higher in eyes with thick cornea compared to eyes with thin cornea, however DCT and Tono-pen readings were not significantly affected by CCT.

As a relatively new tonometer, DCT has been previously compared with GAT which is accepted as the gold standard of IOP measurement. There is a general consensus on that DCT readings are significantly higher than GAT. Kniestedt et al.,[13] compared DCT and GAT readings with manometrically derived IOPs in human cadaver eyes and reported that DCT readings were higher than GAT and closer to the true IOP. The amount of difference changes according to the study but the range is about 0.8 to 2.8 mmHg in healthy eyes.[4-6,14-17]

Table 2: *Correlations between the readings by DCT, GAT, NCT and Tono-Pen (Spearman's correlation).*

	DCT		**GAT**		**NCT**		**Tono-Pen**	
	r	p	r	p	r	p	r	p
DCT			0.728	<0.001	0.386	<0.001	0.567	<0.001
GAT	0.728	<0.001			0.563	<0.001	0.585	<0.001
NCT	0.386	<0.001	0.563	<0.001			0.569	<0.001
Tono-Pen	0.567	<0.001	0.585	<0.001	0.569	<0.001		

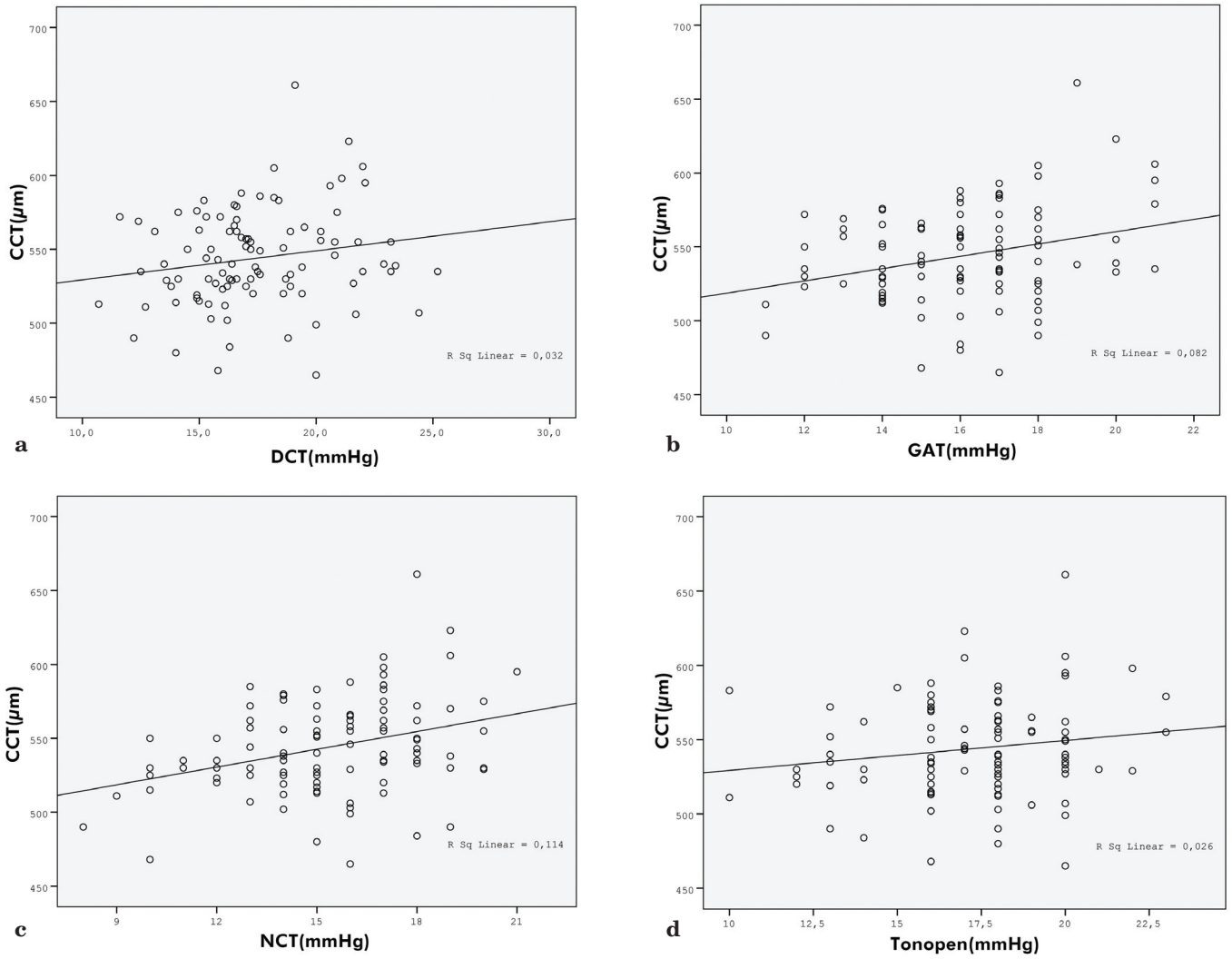
r: Correlation coefficient.

Table 3: *Correlations between intraocular pressure readings by DCT, GAT, NCT and Tono-Pen and the clinical parameters (Spearman's correlation).*

	DCT		GAT		NCT		Tonopen	
	r	p	r	p	r	p	r	p
AL	-0.087	0.389	-0.058	0.564	-0.126	0.212	-0.164	0.102
ACD	-0.004	0.965	-0.091	0.369	-0.044	0.662	-0.106	0.292
CCT	0.207	0.039*	0.232	0.020*	0.315	0.001*	0.139	0.168
K	0.129	0.242	0.051	0.643	-0.039	0.724	0.141	0.202
SBP	-0.009	0.929	-0.021	0.836	0.001	0.993	0.040	0.692
DBP	-0.008	0.939	0.015	0.880	0.025	0.807	0.056	0.583

r; Correlation coefficient.
AL; Axial length, ACD; Anterior Chamber Depth, CCT; Central Corneal Thickness, K; Keratometry, SBP; Systolic Blood Pressure, DBP; Diastolic Blood Pressure.
K values were available in 84 patients. N=100 for any parameter except K.

In our study, the difference in IOP readings between DCT and GAT was 1.3±2.1 mm Hg. Despite the significant difference in the mean IOP levels, GAT and DCT were shown to have a good correlation. There are only a few reports assessing the correlation of DCT with NCT and Tono-Pen. In these reports, DCT readings were found to be higher than that of NCT but similar to Tono-Pen.[6,15] In our study, despite good correlation between the tonometers, DCT readings were higher than NCT but not significantly different from Tono-Pen.



Graphic 2a-d: *Scatter-plot graphs show the correlation between the central corneal thickness and the intraocular pressure measured by a; dynamic contour tonometry (DCT), b; Goldmann applanation tonometry (GAT), c; non-contact tonometry (NCT) and d; Tono-Pen.*

The correlation of the tonometer readings with other ocular and systemic factors is another issue addressed by our study. Corneal properties, which are well-known sources of applanation tonometry errors, affect the force required to flatten the area to measure the IOP.[6,18] We did not find any correlation between any of the IOP readings and K. The lack of correlation between DCT readings and K is a finding which is in concordance with the previous studies.[5,15,19,20] but there are also studies reporting that steeper cornea correlated with higher IOP readings by DCT or/and GAT.[8,9,16,21]

We found that CCT significantly correlated with DCT, NCT and GAT. Previous studies revealed that DCT was less dependent on CCT (if any) whereas GAT and NCT significantly correlated with CCT.[4-6,9,15,17,22] On the contrary, the association of DCT with corneal resistance factor and CCT to some degree has also been reported.[3,14] Briefly, DCT may not be completely free from corneal biomechanical effects. In our study, IOP readings by GAT and NCT were significantly lower in eyes with thin cornea compared with eyes with thick cornea. NCT seems to be more affected by CCT than GAT, which could be explained by the different rate of application of strain and the difference in ocular expansion in the rapid and slow applanation conditions.[9,23] This may have a clinical significance in evaluation of IOP level in eyes with thin cornea and perhaps IOP measurement by DCT may be suggested in this condition.

In conclusion, DCT readings were higher than that of GAT and NCT but not Tono-pen. Although showed a positive correlation, DCT readings were not significantly affected by CCT. However, GAT and NCT showed significantly lower readings in eyes with thin cornea compared to that with thick cornea. These data indicate that DCT might be a favourable tonometer in eyes with thin cornea. Further prospective studies are needed to understand whether DCT would be suggested as the tonometer of choice in routine clinical practice.

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