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CLINICAL STUDY

Comparison of dynamic contour tonometry and noncontact tonometry in ocular hypertension and glaucoma

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Abstract

Purpose **To assess the agreement in the measurement of intraocular pressure obtained by dynamic contour tonometer (DCT) and noncontact tonometer (NCT) in patients with glaucoma and ocular hypertension, to investigate the effect of corneal thickness on pressure readings by both instruments, and to assess the reproducibility of dynamic contour tonometer.**

Methods **NCT and DCT measurements were made on 104 eyes of 104 patients with primary open-angle glaucoma ($n=75$) or ocular hypertension ($n=29$), and agreement was assessed by means of Bland–Altman plots. The effect of corneal thickness on both tonometers was assessed by linear regression analysis. Interobserver and intraobserver variations for dynamic contour tonometer were assessed in 41 eyes of 41 patients.**

Results **The mean difference ± SD (95% limits of agreement) between NCT and DCT was −0.80 ± 2.98 (−6.6 to 5.1) mm Hg ($P=0.009$) and no relation between NCT/DCT differences and average was found. The intraocular pressure readings obtained by noncontact tonometer depended on central corneal thickness ($P<0.001$, adjusted $r^2=0.301$). However, dynamic contour tonometer readings showed no effect of corneal thickness ($P=0.388$, adjusted $r^2=-0.002$). The coefficient of repeatability for DCT was 0.92 (95% CI 0.85–0.96, $P=0.001$).**

Conclusion **In subjects with primary open-angle glaucoma and ocular hypertension, NCT and DCT readings are not interchangeable. DCT measurements, unlike NCT measurements, did not depend on corneal thickness.**

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Keywords: tonometry; intraocular pressure; corneal thickness; primary open-angle glaucoma; ocular hypertension

Introduction

Glaucoma is the leading cause of irreversible vision loss worldwide and is of major public health concern, leading to loss of mobility and independence.[1–3] Intraocular pressure (IOP) has a critical role in case detection and management of primary open-angle glaucoma (POAG).[4] IOP reduction is currently the only treatment available for decreasing the risk of glaucoma progression. Ocular hypertension (OHT) is associated with an increased risk of developing glaucoma,[5] and reducing IOP has been shown to lessen progressive loss of the visual field.[6] Therefore, determination of real IOP is critical for the management of glaucoma.

Applanation tonometry is the method of measuring IOP with instruments that flatten the corneal apex. Goldmann applanation tonometry (GAT) is a widely established and the most common indirect method for identifying IOP for the last four decades and is the gold standard for measuring the IOP.[7–11] GAT, while being minimally invasive, still requires the instillation of fluorescein, ocular topical anaesthesia, and corneal contact. In addition to this, there are some advantages of the other objective instruments, such as noncontact tonometers

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(NCTs), over the GAT. The NCT has the potential advantage that it uses an air puff to applanate the cornea, reducing the possible risk of cross-infection with agents such as adenovirus and variant Creutzfeldt–Jakob disease.[12,13] Corneal anaesthesia and direct corneal contact are not required to obtain an IOP reading compared with GAT. Thus, NCTs are comfortable for the patient with a minimal risk of infection, in addition to being an easy to use and rapid method of IOP measurement. Recently, usage of NCTs in diagnosis and management of glaucoma has been gradually increasing in many countries.[4]

A new digital, slit-lamp-mounted tonometer has been recently introduced as an alternative to applanation tonometry. The dynamic contour tonometer (DCT) (Pascal tonometer, Swiss Microtechnology AG, Port, Switzerland) is a nonapplanation contact tonometer designed to be largely independent of the corneal biomechanical properties. The medical-grade silicon tip of DCT creates a tight-fitting shell with the cornea when in contact with it and compensates for all forces exerted on it. A pressure sensor that is centrally and concavely embedded into the tonometer tip measures the IOP transcorneally. DCT has been reported to be unaffected by central corneal thickness (CCT) in healthy and glaucoma subjects[14–16] and in refractive surgery patients before and after laser *in situ* keratomileusis as well.[17,18] Therefore, it is important to ascertain the agreement of NCT with DCT along with reproducibility of DCT for the assessment of IOP in POAG and OHT subjects.

The aim of this study was to assess the agreement in the measurement of IOP obtained by DCT and NCT in patients with POAG and OHT and to investigate the relationship between CCT and IOP measurements using both instruments. The second goal of this study was to assess interobserver and intraobserver reproducibility of IOP measurement by means of DCT.

Materials and methods

Study population

Patients with POAG and OHT were included in the study. The local university ethics committee approved the study and the tenets of the Declaration of Helsinki were observed. Written informed consent was obtained from all the participants.

Agreement of DCT and NCT IOP readings

One hundred and four patients with POAG ($n=75$) or OHT ($n=29$) were included in this prospective study. POAG was defined as glaucomatous optic nerve damage, glaucomatous visual field defect, IOP of 22 mm Hg or beyond, and an open anterior chamber angle in gonioscopy. OHT was defined as IOP of 22 mm Hg or more in the presence of a normal optic nerve head, normal visual field, and normal gonioscopy. Exclusion criteria were as follows: history of intraocular inflammation or trauma; previous or current corneal disease; contact lens wear; subjects with astigmatism greater than 3.0 dioptres (D); and any ocular surgery, including anterior segment laser applications. To minimize systematic bias, only the left eye of each patient was included in the study. Prior to IOP measurements, the cornea was anaesthetized with eye drops (proparacain). During the measurement, subjects were asked to keep both eyes open, breathe quietly, and fixate into the distance behind the examiner. After patients had given informed consent, IOP was measured in random order (to allow for changes in IOP produced by applanation of the cornea) by the NCT and DCT with 5 min intervals.

The mean of three consecutive measurements of NCT readings was recorded. The same experienced examiner took DCT readings. Quality score (Q) of DCT readings is classified from Q1 (optimum) to Q5 (unacceptable) by the manufacturer. Q4 and Q5 measurements, which indicate poor data quality, were excluded from the study. Although Q3 is classified as 'acceptable' by the manufacturer, intraobserver variability is higher than for Q1 and Q2. Thus, the mean of three consecutive Q3 measurements was calculated or in cases of high-quality measurements (Q1 and Q2), one reading was considered sufficient.[19]

Subsequently, CCT was determined by an ultrasonic pachymeter (Echo Scan US-80, Nidek, Tokyo, Japan). The pachymeter probe was placed on the centre of the cornea over an undilated pupil and the mean of three readings within an SD of $\pm 5\,\mu$m was calculated for each eye.

Reproducibility of DCT and NCT

The left eyes of another 41 patients with POAG ($n=30$) or OHT ($n=11$) with age ranging from 41 to 82 years were chosen for the reproducibility study. Patients with a history of intraocular inflammation or trauma, previous or current corneal disease, contact lens wear, with astigmatism greater than 3.0 D, and any ocular surgery including anterior segment laser applications were excluded from the study. All IOP measurements were performed with an undilated pupil. In this study, estimation of IOP was not commenced until each of the examiners had completed a learning period (at least 10–15 patients) with the DCT. Two operators (IFH and ME) independently measured the IOP by means of DCT

and NCT as described previously in a random sequence with 5 min intervals, with three IOP measurements each. All IOP measurements were obtained at 30 s intervals within the devices. An assistant recorded each measurement. The observers were masked to all IOP measurements.

Statistical analysis

Variables showed almost perfect normal distribution in both Kolmogorov–Smirnov test and Q–Q plots. SPSS (statistical software) 11.5 for Windows was used for the calculation of means, SDs, paired sample *t*-test, linear regression analysis, analysis of variance (ANOVA), coefficient of repeatability, and variance components estimation. *P*-value smaller than 0.05 was considered significant. We used the Bland–Altman graph for analysing the amount of agreement between NCT and DCT IOP readings. MedCalc Version 7.4.2.0 (MedCalc Software, Mariakerke, Belgium) program was used for the Bland–Altman analysis.

Intraobserver reproducibility was based on the analysis of two independent series of measurements made by the two examiners (six examinations). Reproducibility was evaluated by means of the (two-way random, consistency) coefficient of repeatability. The systematic difference between methods was termed the 'bias' and random differences were quantified by the 'limits of agreement'. Where there was no relation between interinstrument or interobserver differences and IOP magnitude, bias was calculated as the mean difference and 95% limits of agreement were computed (provided that the differences followed a normal distribution).

Results

The age, sex, IOP readings with NCT and DCT, CCT, and the mean difference of IOP measurements between tonometers are shown in Table 1.

Table 1 Age and sex, IOP readings with NCT and DCT, CCT, and the mean difference of IOP measurements between tonometers

Parameters	*Mean ± SD (range)*	P-*value*[a]
Age (years)	61.4 ± 12.8 (25–92)	
Sex (female/male)	50/54	
NCT (mm Hg)	19.2 ± 4.4 (9–30)	
DCT (mm Hg)	20.0 ± 3.6 (12.9–30.7)	
NCT–DCT (mm Hg)	−0.8 ± 3.0	0.009
CCT (μm)	563 ± 45 (475–663)	

CCT, central corneal thickness; DCT, dynamic contour tonometer; IOP, intraocular pressure; NCT, noncontact tonometer; SD, standard deviation.
[a]Paired sample *t*-test.

Agreement of DCT and NCT IOP readings

Figure 1 shows a Bland–Altman plot of NCT and DCT differences against the average of NCT and DCT values. The mean difference (95% limits of agreement) between NCT and DCT was −0.80 ± 2.98 (−6.6 to 5.1) mm Hg, and no relation between NCT/DCT differences and average was found. The 95% confidence interval (CI) for bias of mean NCT/DCT difference was −1.57 to −0.03 mm Hg. The 95% CI for the bias of lower and upper agreement limits were −7.70 to −5.50 and 4.40–6.20, respectively.

Effect of CCT and age on NCT and DCT IOP measurements

The IOP readings obtained by NCT depended on CCT ($P = 0.000$; adjusted $r^2 = 0.301$; 95% CI 0.038–0.070; a slope of 0.054 mm Hg per 1 μm CCT) by linear regression analysis. In contrast to NCT, DCT readings showed no effect of CCT ($P = 0.388$; adjusted $r^2 = -0.002$; 95% CI −0.009 to 0.023). The difference between NCT and DCT readings was also affected by CCT ($P < 0.001$; adjusted $r^2 = 0.518$; 95% CI 0.039–0.056; a slope of 0.047 mm Hg per 1 μm CCT). Scatter plot of CCT against IOP difference between NCT and DCT is shown in Figure 2.

Linear regression analysis on DCT and NCT readings showed no effect of age ($P = 0.985$, 95% CI −0.056 to 0.057, adjusted $r^2 = -0.01$; $P = 0.121$, 95% CI −0.121 to 0.014, adjusted $r^2 = 0.014$, respectively).

All patients with POAG ($n = 75$) were treated with monotherapy or with combined topical therapy. In the OHT group, 13 of 29 patients were treated with

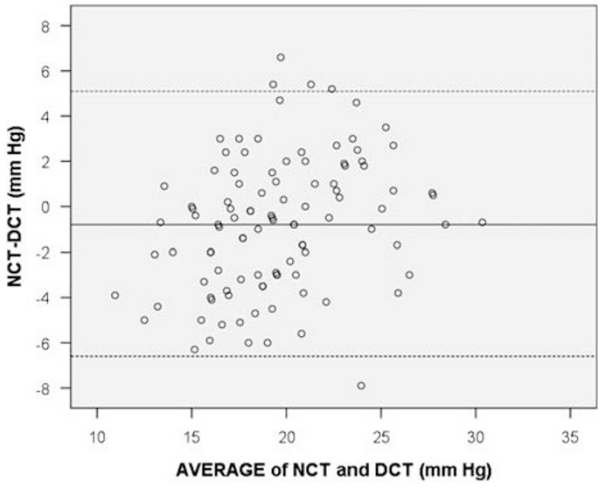

Figure 1 Bland–Altman plots of noncontact tonometer (NCT)/dynamic contour tonometer (DCT) intraocular pressure (IOP) differences against NCT and DCT mean. There was no relation between NCT and DCT readings (Outer lines indicate ± 1.96 SD).

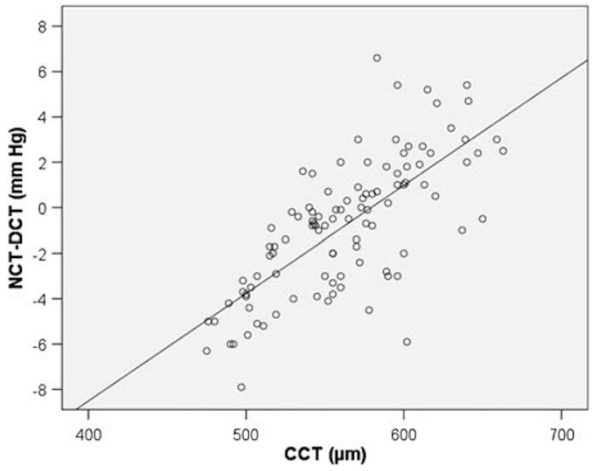

Figure 2 Scatter plots of central corneal thickness (CCT) against intraocular pressure (IOP) differences between noncontact tonometer (NCT) and dynamic contour tonometer (DCT).

monotherapy. In the treated group ($n=88$), mean NCT/DCT difference was -1.2 ± 2.9 mm Hg. In the untreated group ($n=16$), mean NCT/DCT difference was 1.4 ± 2.3 mm Hg. Analysis of variance (ANOVA) performed to test whether treatment status had an effect on NCT/DCT differences showed statistically significant effect ($P=0.001$).

Intraobserver and interobserver reproducibility

The descriptive statistics for each observer are summarized in Table 2. No difference was found between the IOP readings taken in the three sessions for both examiners by means of DCT and NCT ($P>0.05$ for both). For this reason, the average of the three readings was used for the interobserver variability study. The coefficient of repeatability was 0.92 (95% CI 0.85–0.96, $P<0.001$) for DCT and 0.95 (95% CI 0.91–0.97, $P<0.001$) for NCT.

There were no statistically significant interobserver differences between mean NCT and DCT measurements ($P>0.05$ for both). The mean interinstrument difference between NCT and DCT was 0.02 ± 1.04 (-0.31 to 0.34) and it was not statistically significant ($P=0.9$).

Discussion

In this study, we compared DCT with NCT, a widely used tonometer in ophthalmology clinics, and evaluated the effect of CCT on IOP measurements with both tonometers. We found no agreement between the IOP readings obtained by both tonometers and no effect of corneal thickness on DCT readings ($P=0.388$) over a wide range of CCT. In contrast to DCT, IOP readings

Table 2 Descriptive statistics of the intraocular pressure measurements (mm Hg) by means of dynamic contour tonometer and noncontact tonometer performed by the two examiners

Examiner	*DCT*		*NCT*	
	Mean	*SD*	*Mean*	*SD*
IFH1	19.3	4.4	19.2	4.5
IFH2	18.8	4.7	18.9	4.6
IFH3	18.8	4.5	19.0	4.4
IFH mean	19.0	4.5	19.0	4.5
ME1	19.9	4.4	19.2	4.4
ME2	19.0	4.1	19.5	4.6
ME3	18.8	4.0	18.9	4.2
ME mean	19.1	4.1	19.2	4.4
IFH mean −ME mean	−0.2	1.7	−0.2	1.4

SD, standard deviation.

obtained by NCT were dependent on CCT ($P<0.001$), in that NCT measurements showed a linear correlation with an increase in IOP of 0.054 mm Hg per 1 μm CCT. We also investigated the intraobserver and interobserver reproducibility of IOP measurements by DCT. The analyses of intraobserver and interobserver variability by means of DCT seem to be highly reproducible.

Ogbuehi[20] reported no significant difference in intersession repeatability indices between GAT and Topcon CT-80 NCT and the average IOP measured by both tonometers. He found that the mean difference in IOP measurements between the two techniques was 0.2 ± 1.5 mm Hg and the 95% limits of agreement were -3.14 and $+2.74$ mm Hg. These limits of agreement show good relation between GAT and CT-80 NCT IOP readings. Therefore, he suggested that NCT is an accurate and reliable method for assessing IOP and that its IOP readings are interchangeable with those measured with the GAT. Nevertheless, this study underwent IOP range of 9–21 mm Hg in healthy individuals. Therefore, there is no clear evidence that the agreement can be generalized to IOP values that are not in this range.

Goldmann[21] speculated that the tonometers accuracy might be questionable in corneas with a CCT outside a normal range. Now the effect of CCT on the accuracy of IOP measurements with different tonometers is well known.[14,22–24] The CCT has become an important biometric factor and is an essential part of the evaluation of glaucoma. Siganos *et al*[17] reported that GAT and NCT readings significantly correlated with CCT, and the mean change in IOP readings was approximately 3 mm Hg for every 100 μm change in CCT. They also found that DCT was not influenced by CCT. A manometry experiment showed that measurement with DCT provides IOP values significantly closer to true manometric levels than either GAT or pneumotonometer.[25] Francis *et al*[26]

reported that DCT was less affected than GAT by variations in CCT in 2157 participants of primarily Mexican ancestry. We found that CCT showed no significant effect on DCT readings in the present study, which corresponds well with previous studies.[14,17,26–28] IOP measured by NCT, on the other hand, was dependent on CCT. We found that in eyes with POAG and OHT, the NCT readings correlated significantly with CCT, and our findings indicate a slope of 0.054 mm Hg per 1 μm increase in CCT. Possible explanation for these differences in IOP change per 100 μm change in CCT in different studies may be related to patient factors (eg race and diagnosis of POAG and OHT) and unknown factors influencing IOP, such as corneal hydration state and corneal rigidity.

The 95% agreement limits of the NCT and DCT are wider than reported in a previous study, which compared GAT and DCT, where limits from −1.6 to 2.4 mm Hg were found.[25] Some other studies showed wider 95% agreement limits between DCT and GAT.[15,29] Although we did not find any relation between IOP measurements by DCT and those by NCT, a wide range of 95% agreement limits may partly be related with the wide range of CCT in the subjects studied.

This study demonstrated that in common with other tonometers such as GAT and NCT, measurement of IOP using the DCT seems to indicate that both the intraobserver and interobserver reproducibilities of IOP measurements are extremely high. The coefficient of repeatability was 0.92, which compared favourably with that obtained by previous studies.[14,15] The results of our study suggest that the relatively simple, highly reproducible, and objective nature of DCT should allow any well-trained operator to make highly reliable IOP measurements.

In conclusion, DCT presents a new technology of noninvasive IOP measurement. The DCT showed no agreement when compared with NCT in patients with POAG and OHT. In the subjects studied, IOP measurements with DCT did not depend on CCT. DCT may offer some clinically relevant advantages over conventional NCTs for screening and management of POAG or OHT and a potential clinical role for subjects with CCT outside the normal range.

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