Comparison of Dynamic Contour Tonometry with Goldmann Applanation Tonometry

Claude Kaufmann, Lucas M. Bachmann, and Michael A. Thie1

PURPOSE: The dynamic contour tonometer (DCT; Pascal tonometer) is a novel tonometer designed to measure intraocular pressure (IOP) independent of corneal properties. The purpose of this study was a comparison of the DCT with the Goldmann applanation tonometer (GAT) with respect to mean of IOP readings, the influence of ocular structural factors on IOP readings, and both intra- and interobserver variability, in a large group of healthy subjects.

METHODS: In a prospective study of 228 eyes, IOP measurements by GAT and DCT were compared, and the effects of central corneal thickness (CCT), corneal curvature, axial length, and anterior chamber depth were analyzed. To evaluate intra- and interobserver variability, IOP was measured in eight eyes by four observers.

RESULTS: There was a high concordance between the IOP readings obtained by DCT and GAT. However, IOP readings were consistently higher with DCT than with GAT (median difference: +1.7 mm Hg, interquartile range [25th–75th percentile] = 0.8–2.7 mm Hg). In contrast to GAT, multivariable regression analysis showed no significant effect of corneal thickness, corneal curvature, astigmatism, anterior chamber depth, and axial length on DCT readings. For repeated measurements the intraobserver variability was 0.65 mm Hg for the DCT and 1.1 mm Hg for the GAT (P = 0.008). Interobserver variability was 0.44 mm Hg for the DCT and 1.28 mm Hg for the GAT (P = 0.017).

CONCLUSIONS: IOP measurements by DCT are highly concordant with IOP readings obtained from GAT but do not vary in CCT and have a lower intra- and interobserver variability. DCT seems to be an appropriate method of tonometry for routine clinical use. (Invest Ophthalmol Vis Sci. 2004;45:3118–3121) DOI:10.1167/iovs.04-0018

A ccurate measurement of intraocular pressure (IOP) is a fundamental parameter in any ophthalmic examination. Over the past four decades, Goldmann applanation tonometry (GAT) has become the standard for routine measurement of IOP, as the method has proven to be robust and easy to use with low intra- and interobserver variability.1 However, the accuracy of GAT depends on many factors, including corneal thickness, corneal curvature, corneal structure, and axial length.2 Especially central corneal thickness (CCT) has been shown to have a substantial effect on IOP readings obtained with the GAT. The management of patients with suspected ocular hypertension or early glaucoma depends on an accurate IOP assessment.3 It is recommended that not only the GAT readings but also CCT be recorded for a glaucoma work-up.4 However, this requires an ultrasound pachymeter and a reliable nomogram to convert GAT readings and CCT into true IOP. Several nomograms for adjusting GAT readings in normal eyes with varying CCT5–7 or in eyes after refractive surgery8,9 have been published, but so far none seems to be satisfactory.10

With the dynamic contour tonometer (DCT), a new digital tonometer has been introduced as an alternative to adjustments of application tonometry readings based on CCT. The so-called contour-matched tonometer tip has a concave surface that allows the cornea to assume the shape that it naturally assumes when pressure on both sides of the cornea is equal and distortion of the cornea is minimal. Exposing a miniaturized pressure sensor closely to the contour of such a cornea is thought to measure IOP directly (i.e., without systematic errors resulting from force-to-pressure translations; Kanngieser H, et al. IOVS 2002;43:ARVO EAbstract 301). In a pilot study on patients before and after corneal refractive surgery (LASIK) DCT has been shown to measure IOP accurately, independent of corneal thickness.11

The purposes of this study were to compare the IOP readings obtained by DCT with those of GAT, to evaluate the ocular structural factors influencing IOP measurements obtained from both tonometers and to determine intra- and interobserver variability in a group of nonsurgical healthy subjects.

METHODS

One hundred fifty healthy volunteers from the hospital staff with normal eyes on slit lamp examination and no history of previous ocular diseases, trauma, or surgery contributed 228 eyes that were evaluated in a prospective single-center study. Informed consent, according to the tenets of the Declaration of Helsinki, was obtained from each volunteer.

All measurements were taken by the same examiner in the following order: biometry, pachymetry, GAT, and DCT. First, axial length, corneal curvature, and anterior chamber depth were measured with an optical biometry system (IOL Master; Carl Zeiss AG, Feldbach, Switzerland). Second, CCT was measured with an ultrasonic pachymeter (model SP-2000; Tomey Corp., Cambridge, MA). The pachymeter probe was placed on the center of the cornea over an undilated pupil and the mean of three readings within a range of ±5 μm was calculated for each eye. Third, GAT was performed on a slit lamp (Haag-Streit, Koniz, Switzerland) with a tonometer calibrated according to the manufacturer’s guidelines. Before each reading, the measuring drum was reset to approximately 2 mm Hg, and the mean of three consecutive readings was recorded.

Fourth, DCT was performed using a technically identical prototype of the model launched in November 2003 (Pascal dynamic contour tonometer; Swiss Microtechnology AG, Port, Switzerland; slit-lamp-mounted, self-calibrating, 1 g appositional force, 100 Hz sampling rate, 7 mm tip diameter, 1.2 mm pressure sensor diameter). As DCT provides a digital readout of the IOP on a liquid crystal display (LCD), prior knowledge of the GAT result would not influence the result and made it unnecessary to randomize the order of IOP measurements (always

From the 1Department of Ophthalmology and the 2Horten Centre, University of Zurich, Zurich, Switzerland.

Submitted for publication January 8, 2004; revised May 14, 2004; accepted June 9, 2004.

Disclosure: C. Kaufmann, None; L.M. Bachmann, None; M.A. Thie1, None

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be marked "advertisement" in accordance with 18 U.S.C. §1754 solely to indicate this fact.

Corresponding author: Michael A. Thiel, Department of Ophthalmology, University of Zurich, Frauenklinikstr. 24, CH-8091 Zurich, Switzerland; michael.thiel@usz.ch.

3118
GAT followed by DCT) or to mask the investigator. However, for the study of the intra- and interobserver variability, all four investigators were fully masked to all results. For this part of the study, three GAT readings followed by three DCT readings were taken in eight participants by each investigator, resulting in 192 measurements. The delay between readings by different investigators was kept as short as possible (<30 seconds).

Data are presented as medians and 25th to 75th percentile limits. Comparisons in pressure measurements were performed using the nonparametric Wilcoxon signed ranks test to account for the skewed and nonsymmetrical distribution of data points. \( P < 0.05 \) was considered significant. To correct for related data, when two eyes of the same subject were entered into analysis, we performed clustered analyses, using the subject identifier as the cluster variable. We fitted models in which DCT and GAT, respectively, acted as the dependent variable. To adjust for the skewed data distribution, DCT and GAT were transformed into their logarithms. Corneal thickness, corneal curvature, astigmatism, anterior chamber depth, and axial length were entered as continuous independent variables. First each independent variable was assessed in a univariate analysis. Then all independent variables were fitted into two multivariable models (one for GAT and one DCT).

To study the variability between the different investigators and the two measurement readings, we performed analyses of variance (ANOVAs). We used the variance components procedure to estimate the contribution of an independent variable (observer, test, subjects, observer subject interaction, and residual error) to the variance of the dependent variable (pressure measurement). Based on the variance components, we calculated the intraclass correlation coefficients (ICC) for GAT and DCT using the variance component of the subjects in the numerator and the sum of all variances in the denominator. To test for significant differences between the ICCs, we calculated the sum of variance of all noise components for the two tests (all variance components except the subjects variance component). The division of the two noise components was bootstrapped and tested using a one-sample \( t \)-test. To assess the intra- and interobserver variability of DCT and GAT, we calculated the interobserver variability for each of the two tests as the sum of the variance components of the investigator and the investigator–subject interaction. The variance component of the residual error was used as the intraobserver variability.

Statistical analysis was performed on computer (SPSS statistical software, ver. 10; SPSS Inc., Chicago, IL).

**RESULTS**

The study included 228 healthy eyes with a corneal thickness ranging from 439 to 642 \( \mu \)m, a corneal curvature between 40.02 and 46.47 D with a corneal astigmatism of up to 5.6 D, an anterior chamber depth between 2.25 and 4.29 mm, and an axial length between 21.08 and 29.83 mm.

The IOP measurements obtained by DCT and GAT demonstrated a high concordance between the two techniques (Fig. 1). IOP readings obtained by DCT were consistently higher...
Table 1. Variance Components for GAT and DCT Measurements

<table>
<thead>
<tr>
<th>Technique</th>
<th>Variance Components</th>
<th>Estimates (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAT</td>
<td>Investigators</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Subjects</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Investigator × subjects interaction</td>
<td>0.49</td>
</tr>
<tr>
<td>DCT</td>
<td>Investigators</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>Subjects</td>
<td>8.52</td>
</tr>
<tr>
<td></td>
<td>Investigator × subjects interaction</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Residual error</td>
<td>0.65</td>
</tr>
</tbody>
</table>

The interobserver variability for each of the two tests can be calculated as the sum of the variance components of the investigator and the investigator × subjects interaction. The variance component of the residual error is the interobserver variability.

In this study on healthy subjects, IOP readings obtained with the novel DCT have shown a high concordance with IOP readings obtained by GAT. Multivariable regression analysis on DCT readings showed no effect of corneal thickness (P = 0.65), corneal curvature (P = 0.51), astigmatism (P = 0.89), anterior chamber depth (P = 0.44), or axial length (P = 0.06). In contrast to DCT, IOP readings obtained by GAT depended on corneal thickness (P = 0.012), but were also not significantly influenced by corneal curvature (P = 0.24), anterior chamber depth (P = 0.60), or axial length (P = 0.89).

Intraobserver variability was 0.65 mm Hg for the DCT and 1.10 mm Hg for the GAT (P = 0.008). Interobserver variability was 0.44 mm Hg for the DCT and 1.28 mm Hg for the GAT (P = 0.017; Table 1). The ICCs for DCT were 1.11 and 2.38 for GAT respectively (P = 0.08), suggesting that DCT had less variability than did GAT.

## DISCUSSION

In this study on healthy subjects, IOP readings obtained with the novel DCT have shown a high concordance with IOP readings obtained by GAT. Neither CCT, corneal curvature, corneal astigmatism, anterior chamber depth, nor axial length had a significant influence on pressure readings by DCT. IOP readings obtained by DCT were 1.7 mm Hg higher than the readings obtained by GAT. This is in good agreement with two recently published studies that found IOP readings by application of a 1.2 to 2 mm Hg lower than true IOP, as measured manually in human eyes in vivo.12,13 Hence, the higher readings obtained by DCT compared with GAT readings were expected because the DCT was calibrated against a manually controlled pressure standard rather than a GAT pressure reading. To reduce the risk of observer bias, the more subjective GAT measurements have always been taken before the DCT readings, which cannot be influenced by the examiner. Previous studies have shown IOP readings to decrease with successive GAT measurements, but this effect is absent in the case of rapid repetition of IOP measurements by the same examiner, as in the present study.1,14,15 However, the difference between the higher IOP readings obtained by DCT after GAT in this study may be even larger in cases in which IOP is measured by DCT without a prior GAT reading.

In clinical terms, this means that when using DCT for IOP measurements, it may be possible to add 1 or 2 mm Hg to the recommended target IOPs that have been based on GAT readings.

An important factor for the accuracy of IOP measurements is the variability that occurs between measurements performed by the same observer (intraobserver) or by different observers (interobserver), when measuring IOP in the same eye. This study found a smaller intra- and interobserver variability for DCT (0.65 and 0.44 mm Hg) than for GAT (1.11 and 2.38 mm Hg), despite the fact that all examiners had used GAT routinely for at least 5 years, but had no prior experience with DCT. The intra- and interobserver variability found with GAT is very similar to the results found in other studies.1,15 A potential problem of such studies is that repetitive IOP measurements over a short period, which are necessary to calculate the inter- and intraobserver variability, can decrease IOP between the first and the subsequent sets of measurements.1,14 To correct for a possible decline in IOP by the first six measurements the data were reanalyzed without the results obtained during the first sets of GAT and DCT readings. This reduced the amount of inter- and intraobserver variability for both tonometers but did not change the finding that the intra- and interobserver variability found for DCT (0.79 and 0.12 mm Hg, respectively) was smaller than the variability found for GAT (0.97 and 0.50 mm Hg, respectively).

In contrast to GAT, for which the index on the scale is set at 2-mm increments to take into account the intra- and interobserver variability, DCT gives pressure readings with a precision of one decimal place. Despite the considerably lower variability found for DCT in this study, displaying IOP readings with a precision of one decimal place may reflect a “pseudo-precision” that may be clinically misleading. Based on the findings in this study, we recommend recording IOP readings obtained with the DCT in a patient’s file only after rounding them up or down to a value of a full unit (mm Hg). This is still more precise than the GAT readings used to date.

In the present study DCT was found to be suitable as a routine clinical tool for measuring IOP. Because the DCT can be attached to any slit lamp fitted with a normal GAT stand, the new tonometer can be used on most rigs without the need for modification. The examination technique with the DCT is similar to the technique used with the GAT, except that it does not require the sometimes cumbersome tuning of a knob to adjust two oscillating or melting semicircles, which leaves room for observer-dependent interpretation. All examiners involved in this study managed to obtain consistent readings with the DCT right from the beginning, without any learning curve. Measuring IOP with the DCT requires the tip of the tonometer to rest on the patient’s cornea for approximately 5 seconds. This is slightly longer than the contact time that an experienced examiner would require with the GAT. However, the acoustic signal of the DCT that informs the examiner about the correct alignment of the tonometer tip seems to encourage patients to remain still for the time needed.

In summary, this study found IOP measurements taken with the new DCT to have an excellent concordance with measurements obtained by the GAT. In the subjects studied, IOP measurements with the DCT did not depend on corneal thickness, corneal curvature, or axial length. With regard to increasing awareness of the effect of corneal thickness on IOP readings by GAT and the increasing number of patients with a history of corneal refractive surgery, DCT may offer some clinically relevant advantages over conventional Goldmann-type applanation tonometers for screening and management of patients with suspected or known glaucoma.

## References


