

Intraocular Pressure Measurement Precision with the Goldmann Applanation, Dynamic Contour, and Ocular Response Analyzer Tonometers

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Objective: To examine the repeatability and reproducibility of intraocular pressure (IOP) measurements obtained with the Goldmann applanation tonometer (GAT), the Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland), and the Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY). A secondary objective was to assess agreement between the devices.

Design: Evaluation of technology.

Participants: One hundred participants; a mixture of glaucoma suspects, patients, and control volunteers.

Methods: The IOP measurements were obtained with the GAT, DCT, and ORA by 2 of 3 experienced clinicians. Keratometry (CC) measurements were made using the IOLMaster (Carl Zeiss Meditech, AG, Jena, Germany). Three ORA corneal compensated IOP (IOPcc) measurements (in millimeters of mercury) were obtained before the instillation of anesthesia, after which 2 GAT IOP and 3 DCT IOP measurements were obtained in a randomized order. Central corneal thickness (CCT) was measured using an ultrasound pachymeter. The average ORA corneal response factor (CRF) and the average DCT ocular pulse amplitude (OPA) were determined. Intraobserver variability was calculated by the repeatability coefficient. Interobserver variability (measurement reproducibility) and device agreement were calculated with Bland-Altman analysis (mean difference [bias] and 95% limits of agreement [LoA]). The effect of corneal characteristics (CC, CCT, and CRF) on the IOP measurement differences between tonometers also was determined.

Main Outcome Measures: Repeatability and reproducibility of the GAT, DCT, and ORA IOPcc and agreement between tonometers.

Results: The repeatability coefficients for GAT, DCT, and ORA were 2.2, 2.3, and 4.3 mmHg, respectively. The intraobserver variability of ORA measurements was shown to be significantly associated with OPA and to a lesser degree with the quality of ORA waveform scans. The interobserver bias (95% LoA) was $-0.8 (\pm 3.9)$ mmHg for GAT IOP, $-0.2 (\pm 2.8)$ mmHg for DCT IOP, and $-0.3 (\pm 3.9)$ mmHg for ORA IOPcc. On average, GAT under-read both DCT and ORA IOP measurements by approximately 2 mmHg. The IOP measurement differences were predicted better by CRF than CCT.

Conclusions: The DCT shows excellent measurement precision, displaying the best repeatability and reproducibility of the 3 tonometers. Corneal stiffness, as defined using CRF, was associated significantly with agreement between devices. The IOP measurements with each device are not interchangeable.

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The Goldmann applanation tonometer (GAT) is regarded as the reference standard by which to measure intraocular pressure (IOP). However, it is common knowledge that the accuracy of the device, that is, its ability to provide a measure of the true IOP, is affected by corneal properties.^{1,2} The Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland) and the Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY) have been introduced in an attempt to address the shortcomings of the GAT and have been designed to compensate for the corneal effects on IOP measurement.

The DCT, devised by Kanngiesser et al,³ is a slit-lamp mounted contact tonometer that uses a transcorneal method to measure IOP. The DCT uses a strategy known as contour matching, whereby the cornea matches the contour of the tonometer tip, thereby reducing the corneal mechanical effects on IOP measurement. The DCT gathers 100 IOP readings per second over a 5- to 8-second period, and therefore records dynamic IOP. As a result, the device generates both an IOP measurement and a measure of the ocular pulse amplitude (OPA), that is, the difference between the systolic and diastolic IOP. Recent studies have

shown that DCT IOP measurements are associated more weakly with CCT compared with those made by GAT.⁴⁻⁷

The ORA is a noncontact tonometer that measures the biomechanical response of the eye at the cornea to a jet of air.⁸ The device generates 2 metrics of corneal biomechanics, corneal hysteresis, and the corneal response factor (CRF). These metrics are adopted in the IOP calculation, generating a corneal compensated IOP (IOPcc) measure that has been shown to represent an IOP measurement more weakly associated with CCT.⁹

To assess the clinical usefulness of any new device it is important to evaluate the precision of measurements so that measurements of true change may be differentiated from measurement variability. Measurement precision can be divided into repeatability, a measure of device variability when used by a single observer, and reproducibility, a measure of device variability when used by multiple observers. To date, the literature suggests that the GAT has superior measurement precision compared with other available tonometers.¹⁰

The purpose of this study was to determine the repeatability and reproducibility of IOP measurements made with the GAT, DCT, and ORA. A secondary objective was to examine agreement between devices.

Patients and Methods

The study had local ethical committee approval, and informed consent, according to the tenets of the Declaration of Helsinki, was obtained from each participant before examination. The study cohort comprised a mixture of normal volunteers, glaucoma suspects, and glaucoma patients who attended the Glaucoma Research Unit at Moorfields Eye Hospital. Normal volunteers were recruited through friends and spouses of patients and had full visual fields and no previous ocular history of note. The protocol specified that participants with corneal pathologic features such as Fuchs' endothelial dystrophy or keratoconus should be excluded. One hundred eyes of 100 participants were included in the study. Of the participants who consented to the study, none were excluded because of corneal pathologic features.

Study participants underwent axial length and corneal curvature measurements with the IOLMaster (Carl Zeiss Meditech, AG, Jena, Germany). Participants then underwent ORA measurements by 2 of 3 experienced clinicians. The order of clinicians was randomized, and although the clinicians were able to view the ORA waveform plots, they were masked to the IOP measurements that appeared on the screen. Three good-quality waveform scans, defined by the manufacturer as having symmetry in height between the 2 peaks of the waveform, were saved by each clinician.

After instillation of topical corneal anesthesia (proxymetacaine hydrochloride 0.5% with fluorescein sodium 0.25%) 2 GAT IOP and 3 DCT IOP measurements were obtained by the same 2 clinicians who performed the ORA measurement. The order of GAT and DCT was randomized per participant, and participants were given a 5-minute rest between observer measurement. The GAT readings were obtained in a masked fashion, such that the observer not making the measurement set the GAT dial to a random number and then recorded the final reading. In cases where participants displayed a large ocular pulse, the GAT end point was defined at the midpoint of the pulse. Only DCT measurements with a quality reading of 1 or 2 were accepted, and the first DCT reading was discarded in accordance with manufacturer's guidance. As

with the GAT measurement, DCT readings were recorded by the observer not making the measurement. New DCT software (version 4.0) that enables an auditory tone to signal when good-quality readings are obtained was used midway through the study. For this study, the software was set to signal when readings of quality score 1 or 2 were acquired. Central corneal thickness (CCT) was measured using an ultrasound pachymeter (Altair; Optikron 2000, Rome, Italy) at the end of the visit.

Data Analysis

Repeatability (intraobserver variability) of IOP measurements made with each tonometer was calculated as 2.77 times the within-subject standard deviation ($wsSD$)¹¹:

$$wsSD = SD(\text{observation1} - \text{observation2})/\sqrt{2},$$

where SD is the standard deviation, and observation 1 and observation 2 are the recorded IOP measurements. The $wsSD$ was calculated only if the magnitude of standard deviation was unrelated to the magnitude of mean IOP readings. Repeatability for the DCT was calculated for the entire study cohort, with a subanalysis that compared the repeatability of data collected with the old (version 3.1.1) versus new (version 4.1) software. For the ORA, the average of repeatability values calculated for measurements 1 and 2, 2 and 3, and 1 and 3 was used as a measure of device repeatability.

Reproducibility (interobserver variability) was assessed using Bland-Altman plots, using the mean IOP measurement made by each clinician.¹² The mean difference and 95% limits of agreement were calculated.

Agreement between devices also was examined using Bland-Altman analysis, with the mean difference and 95% limits of agreement between devices being calculated. Previous work has shown the agreement of GAT and DCT to be influenced by CCT.⁶ To establish what other factors may impact on device agreement, a univariate generalized linear model analysis was performed, with the measured IOP difference between devices as the dependent variable, and age, average IOP, axial length, and corneal parameters as covariates. Corneal parameters included corneal curvature, CCT, and CRF. The latter was determined from the average of the 3 ORA readings. The CRF is thought to be associated more closely with the elastic properties of the cornea. Corneal hysteresis was not used because it is a measure of viscoelasticity that reduces at higher IOP.¹³

Noncontact devices measure IOP within 5 ms, equating to approximately 1/500 of the cardiac cycle. As a result, the ocular pulse becomes a significant source of variability, with the difference in repeated IOP readings ranging between 1 and 4 mmHg.^{14,15} With the ORA, the separation between the 2 applanation peaks is approximately 20 ms. It is plausible, therefore, that the repeatability limits of ORA IOP measurements may be greater in those with a larger ocular pulse. Furthermore, since the termination of our study, Reichert have upgraded their ORA software to include a waveform score that assigns a numerical value to the quality of the waveform. Using this numerical score as a judge of waveform quality may yield better ORA data than a qualitative estimation of the waveform. Thus, in a post hoc analysis, the ORA data set was reexamined using the new software and the average waveform scores for each participant were determined. In addition, the average DCT OPA value for each participant also was calculated. To examine whether either of these had any effect on the variability of ORA IOPcc measures, a multiple linear regression analysis with the within-participant variance of ORA IOPcc measures as the dependent and average waveform score and OPA as the independents was calculated. Statistical analyses were performed using SPSS software version 17 (SPSS, Inc, Chicago, IL)

Table 1. Demographic Data of Study Cohort

Total Cohort (n = 100; Normal Volunteers, n = 31; Glaucoma/Suspects, n = 69)	Mean	Standard Deviation	Range
Left eye (no.)	50		
Male gender (no.)	62		
Age (yrs)	52.2	17.9	22.0–89.1
Axial length (mm)	24.7	1.7	21.6–30.4
Average keratometry (mm)	7.8	0.3	7.0–8.6
Corneal astigmatism (diopters)	0.8	0.5	0.0–3.3
CCT (μm)	553	39	467–668
GAT (mmHg)			
Observer 1	15.9	5.0	7.5–33.5
Observers 2 and 3	16.4	5.4	7.0–36.0
DCT (mmHg)			
Observer 1	18.2	4.5	9.7–32.2
Observers 2 and 3	18.4	4.5	10.6–34.1
ORA IOPcc (mmHg)			
Observer 1	18.3	4.7	9.4–32.6
Observers 2 and 3	18.6	4.8	9.7–33.1

CCT = central corneal thickness; DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; ORA IOPcc = Ocular Response Analyzer corneal compensated intraocular pressure; SD = standard deviation.

and MedCalc software version 10.3.2 (Medcalc Software, Mariakerke, Belgium).

Results

Demographic data for the study cohort are presented in Table 1. The DCT measurements of quality reading 2 or better were not possible in a total of 7 participants (2 control subjects, 5 glaucoma patients; observer 1 had difficulty with 4 eyes, observer 2 had difficulty with 5 eyes). However, a DCT quality value of 3 was deemed acceptable for these eyes and their data are included in the analysis.

Repeatability of Measurements

The repeatability of IOP measurements obtained with the 3 devices for observer 1 (AK) and observers 2 and 3 (EW and PGS) combined are displayed in Tables 2 and 3. The DCT repeatability improved slightly when using the new software.

Reproducibility of Measurements

The reproducibility of IOP measurements between observer 1 and observers 2 and 3 combined are displayed in Table 4 and Figures

Table 2. Repeatability of Measurement Techniques

Method (n = 100)	Observer 1	Observers 2 and 3
GAT (mmHg)	2.2	2.3
DCT (mmHg)	1.8	2.0
ORA IOPcc (mmHg)	4.4	4.3

DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; ORA IOPcc = Ocular Response Analyzer corneal compensated intraocular pressure.

Table 3. Repeatability of Dynamic Contour Tonometer Stratified by Software Version, with Goldmann Applanation Tonometer and Ocular Response Analyzer Repeatability for Same Participant Cohort

	Observer 1	Observers 2 and 3
DCT software version 3.1.1 (mmHg), n = 48	1.6	2.1
DCT software version 4.0 (mmHg), n = 52	1.9	1.9
GAT (mmHg), n = 48	2.2	2.3
GAT (mmHg), n = 52	2.3	2.1
ORA (mmHg), n = 48	4.1	4.2
ORA (mmHg), n = 52	4.7	4.3

DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; IOP = intraocular pressure; ORA = Ocular Response Analyzer.

Nonsignificant differences (independent *t* test on differences in IOP measurement for each device in each group).

1, 2, and 3. The mean difference in GAT IOP measurements between observers was statistically significant (mean difference, -0.80 mmHg; 95% confidence interval, -1.20 to -0.40 mmHg; $P = 0.0002$, Student *t* test).

To examine whether the 95% limits of agreement were significantly different between tonometers, the variance of interobserver IOP differences was calculated and the *F* statistic was used (Table 5). The data show that the variance of interobserver IOP differences was significantly smaller for the DCT compared with both the GAT and ORA.

Agreement between Devices

Figures 4, 5, and 6 display Bland-Altman plots illustrating the agreement between devices. They clearly show that, on average, GAT IOP measurements were approximately 2 mmHg lower than IOP measured with either the DCT or the ORA IOPcc.

To examine what factors may affect the agreement, a univariate generalized linear model was fitted to the data, with measured IOP differential between devices as the dependent and age, IOP, axial length, and corneal characteristics as the covariates. Table 6 details the *F* statistics and significance of their effects. In all cases, CRF was associated with the IOP measurements differences. Figure 7 illustrates the direction of the relationship.

Post Hoc Analysis: Effects of Ocular Pulse and Waveform Quality on Ocular Response Analyzer Intraocular Pressure Keratometry Repeatability

After reanalysis of ORA data with ORA software version 2.04, a multiple linear regression analysis was performed to examine

Table 4. Reproducibility of Devices

Method	Interobserver Mean Difference (mmHg)	95% Limits of Agreement (mmHg)
GAT (mmHg)	-0.80	± 3.9
DCT (mmHg)	-0.20	± 2.8
ORA IOPcc (mmHg)	-0.30	± 3.9

DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; ORA IOPcc = Ocular Response Analyzer corneal compensated intraocular pressure.

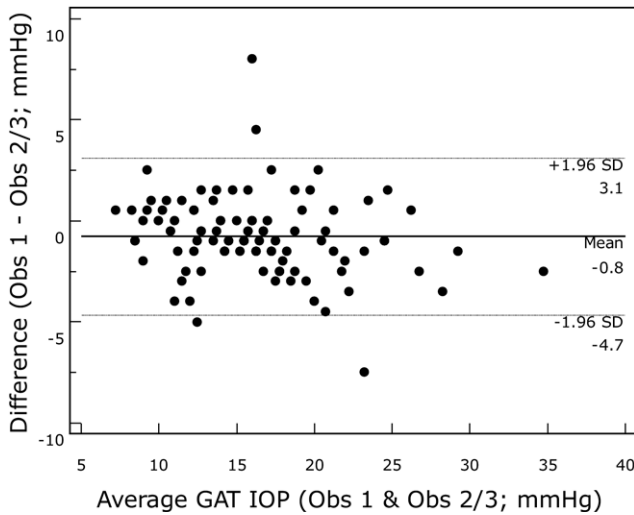


Figure 1. Bland-Altman plot illustrating the reproducibility of Goldmann applanation tonometer (GAT) intraocular pressure (IOP) measurements. Mean difference between observers, -0.80 mmHg; 95% confidence intervals, -1.20 to -0.40 mmHg; Student paired t test IOP differences between observers, $P = 0.0002$ (significant). Obs = observation; SD = standard deviation.

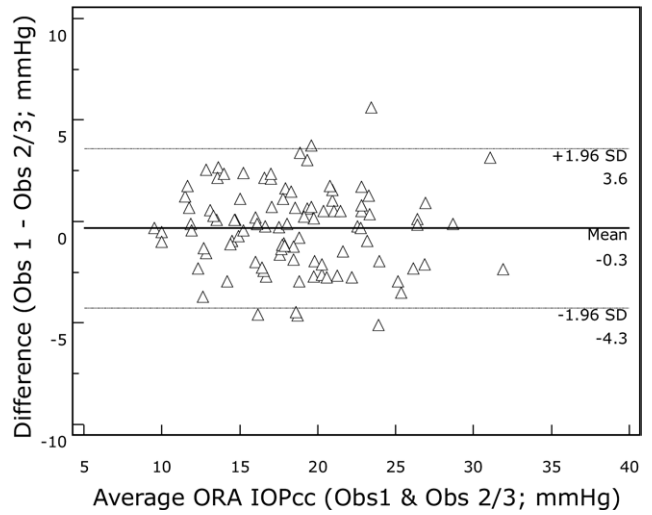


Figure 3. Bland-Altman plot illustrating the reproducibility of Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY) corneal compensated intraocular pressure (IOPcc) measurements. Mean difference between observers, -0.30 mmHg; 95% confidence interval, -0.70 to 0.10 mmHg; Student paired t test IOP differences between observers, $P = 0.099$ (not significant). Obs = observation; SD = standard deviation.

the relationship between within-participant variance of ORA IOPcc measures and the OPA and waveform quality score (Table 7).

The negative coefficient found with waveform score suggests that as the waveform score decreases in quality, the variance of IOPcc measures increases. Similarly, as a participant's OPA increases, the variance of IOPcc measures also increases. The magnitude of IOPcc did not have an effect on IOPcc variability.

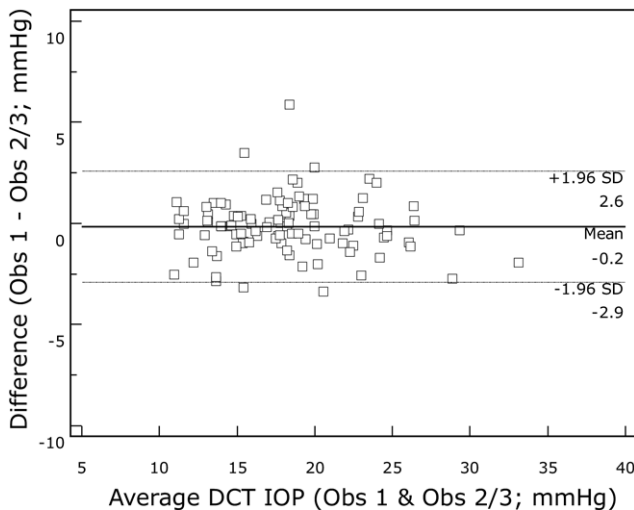


Figure 2. Bland-Altman plot illustrating the reproducibility of Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland) intraocular pressure (IOP) measurements. Mean difference between observers, -0.20 mmHg; 95% confidence interval, -0.5 to 0.10 mmHg; Student paired t test IOP differences between observers, $P = 0.20$ (not significant). Obs = observation; SD = standard deviation.

Discussion

The data presented show that the measurement precision of the DCT seems to be as good as, if not superior to, the current reference standard GAT when used in eyes with no corneal pathologic features and by clinicians experienced in tonometric procedures. The device showed repeatability coefficients comparable with the GAT and had the best reproducibility of the 3 devices tested.

The reported repeatability coefficient for GAT ranges between 2.2 and 2.9 mmHg.^{10,16,17} In a previous study by the authors' group, GAT repeatability was found to be 1.6 mmHg, but in that study, GAT readings were not obtained in a masked fashion.⁶ The present study adopted a masked

Table 5. Variance and F Statistic Examining the Spread of Interobserver Intraocular Pressure Differences for Each Tonometer

Tonometer	Variance of Interobserver Intraocular Pressure Differences	
GAT	4.83	
DCT	1.98	
ORA IOPcc	3.99	
Comparison	F Test	P Value
GAT vs. DCT	2.43	< 0.001
DCT vs. ORA IOPcc	2.01	0.001
ORA IOPcc vs. GAT	1.21	0.35

DCT = dynamic contour tonometer; GAT = Goldmann applanation tonometer; IOP = intraocular pressure; ORA IOPcc = Ocular Response Analyzer corneal compensated intraocular pressure.

The spread of interobserver IOP differences made with the DCT are significantly smaller than those of the GAT and ORA IOPcc.

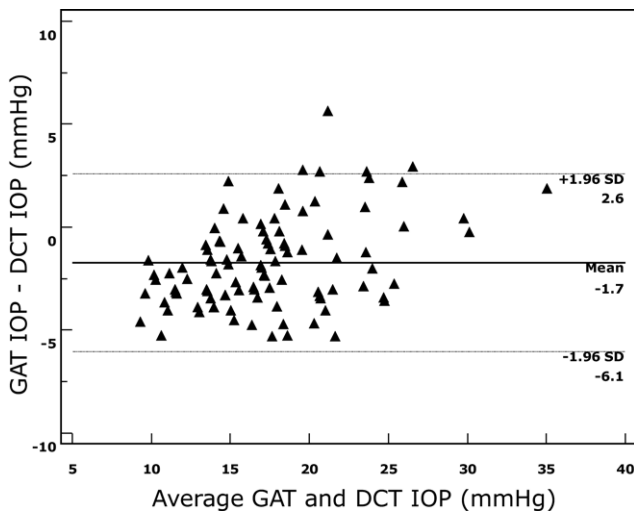


Figure 4. Scatterplot showing the agreement between Goldmann applanation tonometer (GAT) and Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland) intraocular pressure (IOP) measurements. Mean difference, 1.7 mmHg; 95% limits of agreement, +4.3 mmHg. SD = standard deviation.

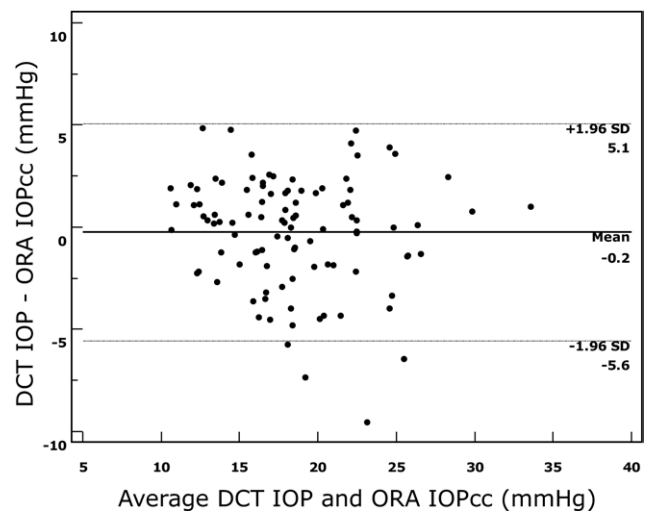


Figure 6. Scatterplot showing the agreement between Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland) intraocular pressure (IOP) and ocular response analyzer (ORA) corneal compensated IOP (IOPcc) measurements. Mean difference, 0.2 mmHg; 95% limits of agreement, +5.3 mmHg. SD = standard deviation.

GAT measurement procedure similar to that of Tonnu et al¹⁰ and found similar GAT repeatability coefficients.

The DCT repeatability found in the present study was better than that reported previously by the authors' group: 2.0 versus 3.2 mmHg.⁶ There are a number of possible explanations for this difference. In the initial study, a prototype DCT was used, whereas a production unit was used for the present study. Improvements in software data acquisition and clinician experience also may explain the improved repeatability; indeed, a subanalysis of DCT data

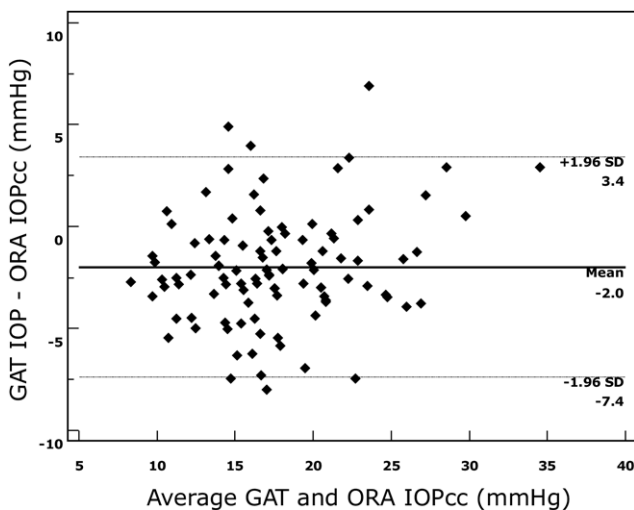


Figure 5. Scatterplot showing the agreement between Goldmann applanation tonometer (GAT) intraocular pressure (IOP) and Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY) corneal compensated IOP (IOPcc) measurements. Mean difference, 2.0 mmHg; 95% limits of agreement, +5.4 mmHg. SD = standard deviation.

showed that repeatability slightly improved with the use of the newer 4.0 version software.

The coefficient of repeatability for the ORA was twice that found using the 2 contact techniques, but less than that reported by Moreno-Montanes et al,¹⁸ who investigated the repeatability of ORA measurements in a cohort of 30 healthy subjects. However, the current ORA IOPcc repeatability value was similar to repeatability coefficients found with other noncontact tonometry devices.¹⁰ In a post hoc analysis, it became apparent that variability of repeated ORA IOP measurements was dependent on the magnitude of the OPA, such that eyes with a larger ocular pulse displayed more intrasession variability in IOPcc readings. This confirms our hypothesis of the effects of the ocular pulse on the variability of noncontact IOP readings. The effects of ORA waveform quality on ORA IOPcc variability approached significance such that repeated ORA measures with a lower average numerical waveform score displayed greater intrasession variability. This provides some evidence to the importance of recording repeated, good-quality ORA measurements when assessing a patient.

This study also examined the interobserver variability, or reproducibility, of devices. The mean difference between observers was statistically significant using the GAT, with observer 1 consistently underreading observers 2 and 3, despite the randomization of observer order. However, interobserver mean difference was negligible using the DCT and ORA. Of the 3 devices, the DCT had significantly narrower limits of agreement, with those of the GAT and ORA being larger than in previous reports.^{6,10,18} Differences may be the result of a number of factors that include appraiser and participant group vari-

Table 6. Factors Related to the Agreement between Devices

	F Statistic		
	Goldmann Applanation Tonometer minus Dynamic Contour Tonometer	Goldmann Applanation Tonometer minus Ocular Response Analyzer Corneal Compensated Intraocular Pressure	Dynamic Contour Tonometer minus Ocular Response Analyzer Corneal Compensated Intraocular Pressure
Age (yrs)	0.01 (P = 0.93)	10.96* (P = 0.001)	7.55* (P = 0.01)
Average IOP (mmHg)	2.36 (P = 0.13)	1.59 (P = 0.21)	5.42* (P = 0.02)
Axial length (mm)	0.05 (P = 0.83)	2.95 (0.09)	2.50 (0.12)
CCT (μm)	0.00 (P = 0.99)	0.71 (P = 0.40)	0.47 (P = 0.49)
Corneal curvature (mm)	0.09 (P = 0.77)	0.59 (P = 0.44)	0.75 (P = 0.39)
CRF (mmHg)	4.04* (P = 0.04)	25.59* (P = 0.001)	5.90* (P = 0.02)

CCT = central corneal thickness; CRF = corneal response factor; IOP = intraocular pressure.

*Highlights factors that are significant at the $P < 0.05$ level.

ability, but illustrate that of the 3 devices tested within this cohort, the DCT seems to give the most precise measure of IOP.

There was a notable bias between tonometers, with the GAT reading on average 2 mmHg lower than both the DCT and ORA IOPcc. An analysis of factors explaining the difference in measurements between GAT and DCT and between GAT and ORA IOPcc found that CRF was the most important explanatory variable. The CCT did not explain any of the IOP measurement differences when CRF was in the model. The GAT read lower than both DCT and ORA IOPcc in eyes with low CRF, and

higher than these 2 tonometers in eyes with a larger CRF. This effect also was noted when examining the DCT and ORA IOP measurement differences. The CRF is thought to be a surrogate measure of corneal elasticity,¹⁹ with a higher CRF value suggesting a stiffer cornea. The data show that GAT overestimates both the DCT and ORA in eyes with a stiffer cornea. This is in agreement with the authors' previous work.⁶ That the DCT was shown to read higher than the ORA IOPcc (albeit to a lesser extent than the GAT) in eyes with a higher CRF suggests that the DCT is not completely free from corneal biomechanical effects. This observation is supported by other studies that have shown a small effect of CCT on DCT IOP measurements.^{6,7,20}

The GAT and ORA IOPcc differences, and to a smaller extent the DCT and ORA IOPcc differences, were also associated with age, with both the GAT and DCT underreading ORA IOPcc in young eyes and overreading in older eyes. The cornea becomes stiffer with advancing age.²¹⁻²⁴ Thus, because both CRF and age are factors with statistical significance in the model, these data suggest that the CRF may not capture all the age-related change in corneal stiffness. Indeed, we previously reported a nonsignificant trend toward a reduction in CRF with age.¹³ It may be that the effects of aging on corneal stiffness are, in some way, undercompensated in the calculation of IOPcc.

The DCT and ORA IOPcc differences also were associated with IOP, with the DCT reading lower than ORA

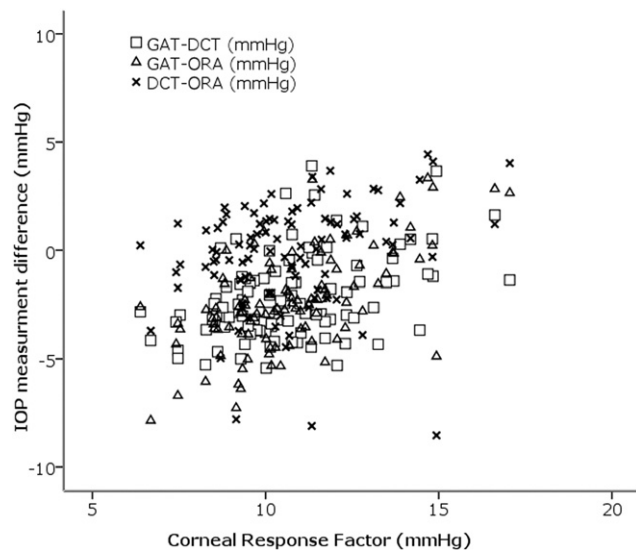


Figure 7. Scatterplot showing the effect of corneal response factor on intraocular pressure (IOP) measurement differences (GAT-DCT regression slope, 0.46; 95% confidence interval (CI), 0.27–0.64; $P < 0.001$; GAT-ORA slope, 0.72; 95% CI, 0.50–0.93; $P < 0.001$; DCT-ORA slope, 0.27; 95% CI, 0.02–0.52; $P = 0.04$). These data show that at low corneal response factor (CRF) levels, the Goldmann applanation tonometer (GAT) underreads IOP measurements made with both the Pascal dynamic contour tonometer (DCT; Swiss Microtechnology AG, Port, Switzerland) and the Reichert Ocular Response Analyzer (ORA; Reichert Ophthalmic Instruments, Buffalo, NY) and overreads at higher CRF levels. To a lesser extent, the DCT underreads the ORA at low CRF levels and overreads it at higher CRF levels.

Table 7. Relationships between Waveform Score, Ocular Pulse Amplitude, and Magnitude of Intraocular Pressure and within-Participant Variance of Corneal Compensated Intraocular Pressure Measurements

	Regression Coefficient (95% Confidence Interval)	P Value
Waveform score	-0.33 (-0.70 to 0.05)	0.09
OPA (mmHg)	0.82 (0.27–1.37)	0.005
Average IOPcc (mmHg)	0.06 (-0.11 to 0.13)	0.85

IOPcc = corneal compensated intraocular pressure; OPA = ocular pulse amplitude.

IOPcc at higher IOPs. In an intracameral study performed on 75 nonglaucomatous eyes undergoing cataract extraction, Boehm et al⁷ noted that the DCT underestimated true IOP at higher levels of IOP. In the present study, differences in DCT and ORA IOPcc measurement in eyes with higher IOP may be a further reflection of the effects of corneal biomechanics on DCT IOP measurements that do not seem to affect ORA IOPcc. The ORA IOPcc may give an IOP measurement that is closer to the true IOP value, because it directly measures and compensates for the individual corneal response. However, this is speculation; the cohort consisted of a mixture of glaucoma patients and healthy subjects, and these groups may display different ocular biomechanical characteristics.²⁵ Intracameral studies examining the IOP measurement accuracy of the ORA will reveal whether the device gives a true measurement of IOP.

The primary aim of the study was to examine measurement precision; thus, the study may not be powered sufficiently to detect an effect of other ocular parameters on IOP measurements. Nonetheless, the data agree with most other literature reports that show the GAT to be affected by corneal properties.

In summary, the results of this study suggest that the DCT shows excellent measurement precision compared with the reference standard GAT and is less affected by corneal properties. It should be pointed out that this study does not show that the DCT provides an accurate measure of IOP, but merely that it displays less intraobserver and interobserver variability. This has implications for clinical practice and clinical trials where IOP measurement is an outcome measure. Further studies of DCT IOP measurement precision with nonexperienced observers and in eyes with corneal pathologic features are required.

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